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MESSENGER Data Management and Science Analysis Plan

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Scott Murchie, MDIS Instrument Scientist Date	Mark Robinson, MDIS Cognizant Co-I Date
Noam Izenberg, MASCS Instrument Scientist Date	William McClintock, MASCS Cognizant Co-I Date
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Andrew Cheng, RS Instrument Scientist Date	Richard Starr, XRS Instrument Scientist Date
	Released Date

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1.0 Purpose and Scope of Document

The MErcury Surface, Space ENvironment, GEochemisty, and Ranging (MESSENGER) mission's Data Management and Science Analysis Plan (DMSAP) presents a high-level strategy for the generation, validation, and delivery of mission data and data products from the MESSENGER project's Science Operations Center (SOC) to the Planetary Data System (PDS) in complete, well-documented, and permanent archives. The plan also specifies policies and procedures for distributing data and data products within the MESSENGER project and to the science community and general public.

This document is to be used by personnel associated with the MESSENGER project to understand the roles and responsibilities of the MESSENGER project, the MESSENGER SOC, and the PDS. Investigators associated with MESSENGER will use this document to understand what is expected of them in terms of delivery of a complete data archive, and how the SOC and PDS can help them prepare their data products. PDS personnel will use this document to understand the types and volumes of data products they can expect to receive from the MESSENGER project.

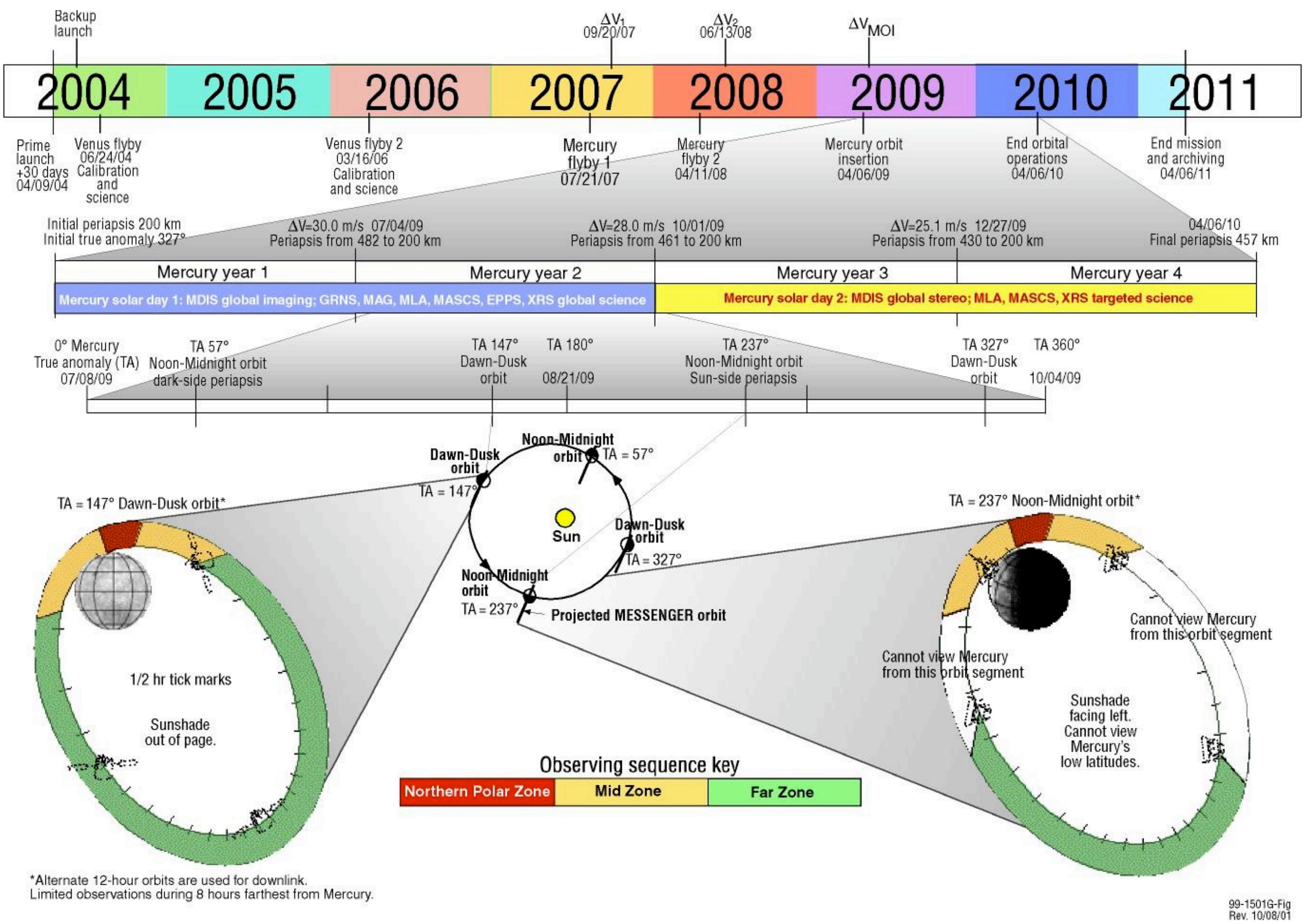

Figure 1. Mission Time Line

2.0 Overview of the MESSENGER Mission

2.1 Mission Operations Background

The MESSENGER mission is designed to orbit Mercury following two flybys each of Venus and Mercury. The overall timeline for the mission is given in Figure 1. MESSENGER uses two gravity assists from Venus and two from Mercury to pick up most of the change in velocity it needs to match speed and orbital parameters with Mercury before orbit insertion. During its two flybys of Mercury, MESSENGER will map nearly the entire planet in color, image most of the part of the planet unseen by Mariner 10, and take reconnaissance measurements of the composition and structure of the surface, atmosphere, and magnetosphere.

MESSENGER's nominal orbit about Mercury is highly elliptical, 200 km above the surface at its lowest point (periapsis) and over 15,000 km at its highest point. The plane of the orbit is inclined 80° to Mercury's equator, and the initial periapsis is at the latitude of 60°N. During the Earth year of operations, solar perturbations cause an upward drift in periapsis elevation (corrected three times) and a northward drift in periapsis latitude (not corrected).

MESSENGER's propulsion system is integrated into the spacecraft structure, making economical use of mass. The miniaturized instruments are mostly co-located on a science deck facing Mercury, while the spacecraft is shielded from direct sunlight by a lightweight sunshade. Most of the instruments are fixed-mounted, so that coverage of Mercury is obtained by spacecraft motion over the planet. The imaging system uses a pivot platform to accommodate flyby imaging and optical navigation, as well as variable look geometries for imaging during the orbital phase.

Further information on MESSENGER mission and spacecraft design may be found in Santo et al. (2001).

Table 1. MESSENGER payload and personnel

Instrument	Science Team Points of Contact	PDS Node Contact
Mercury Dual Imaging System (MDIS) Narrow-angle imager and wide-angle multispectral imager. Pointing is assisted with a pivot platform. Maps landforms, surface spectral variations, and topographic relief from stereo imaging.	IS: Scott Murchie, JHU/APL, scott.murchie@jhuapl.edu Deputy IS: Louise Prockter, JHU/APL, louise.prockter@jhuapl.edu Co-I: Mark Robinson, Northwestern University, robinson@earth.nwu.edu	Imaging Node (I) Eric Eliason (eeliason@usgs.gov)
Gamma-Ray and Neutron Spectrometer (GRNS) Gamma-Ray Spectrometer (GRS) measures the emissions from radioactive elements and gamma-ray fluorescence stimulated by cosmic rays. Used to map elemental abundances in crustal materials. Neutron Spectrometer (NS) provides sensitivity to hydrogen in ices at the poles and average sub-spacecraft atomic weight of crustal material.	IS: Edgar Rhodes, JHU/APL, Deputy IS: Larry Evans, GSFC, larry.evans@gsfc.nasa.gov Co-I: William Boynton, University of Arizona, wboynton@gamma1.lpl.arizona.edu	Geoscience Node (GS) Ed Guinness (guinness@wunder.wustl.edu)
X-Ray Spectrometer (XRS) Measures the fluorescence in low-energy X-rays that is stimulated by solar gamma rays and high-energy X-rays. Used to map elemental abundances of crustal materials	IS: Richard Starr, GSFC, richard.starr@gsfc.nasa.gov Deputy IS: George Ho, JHU/APL, george.ho@jhuapl.edu Co-I: Ralph McNutt, JHU/APL, ralph.mcnutt@jhuapl.edu	Geoscience Node (GS) Ed Guinness (guinness@wunder.wustl.edu)
Magnetometer (MAG) Maps out the detailed structure and dynamics of Mercury's magnetic field and searches for regions of magnetized crustal rocks.	IS: Brian Anderson, JHU/APL, brian.anderson@jhuapl.edu Co-I: Mario Acuña, GSFC, mha@lepmon.gsfc.nasa.gov	Planetary Plasma Interactions Node (PPI) Steve Joy (sjoy@igpp.ucla.edu)
Mercury Laser Altimeter (MLA) An infrared laser transmitter coupled with a receiver that measures the round-trip time of a burst of laser light reflected off Mercury's surface, yielding a distance measurement. Produces highly accurate measurements of topography, and measures Mercury's physical libration.	IS: Xiaoli Sun, GSFC xiaoli.sun@gsfc.nasa.gov Deputy IS: Andrew Cheng, JHU/APL, andy.cheng@jhuapl.edu Co-I: David E. Smith, GSFC, dsmith@tharsis.gsfc.nasa.gov	Geoscience Node (GS) Ed Guinness (guinness@wunder.wustl.edu)
Mercury Atmospheric and Surface Composition Spectrometer (MASCS) Ultraviolet-Visible Spectrometer (UVVS) measures composition and spatial and temporal variations of exospheric species. Visible-Infrared Spectrograph (VIRS) maps surface reflection to determine mineral composition.	IS: Noam Izenberg, JHU/APL, noam.izenberg@jhuapl.edu Co-I: William McClintock, LASP, william.mcclintock@colorado.edu	Atmospheres Node (A) Lyle Huber (lhuber@nmsu.edu)
Energetic Particle and Plasma Spectrometer (EPPS) Measures the composition, spatial distribution, energy, and time-variability of charged particles within and surrounding Mercury's magnetosphere. Plasma is measured by the Fast Imaging Plasma Spectrometer (FIPS) and higher-energy particles by the Energetic Particle Spectrometer (EPS)	IS: Barry Mauk, JHU/APL, barry.mauk@jhuapl.edu Deputy IS: Stefano Livi, JHU/APL, stefano.livi@jhuapl.edu Deputy IS: Thomas Zurbuchen, thomasz@umich.edu Co-I: Robert Gold, JHU/APL, rob.gold@jhuapl.edu	Planetary Plasma Interactions Node (PPI) Steve Joy (sjoy@igpp.ucla.edu)
Radio Science (RS) Uses the Doppler effect (the shift in the frequency of the spacecraft's radio signal with changes in the spacecraft's velocity relative to Earth) to measure Mercury's mass distribution, including spatial differences in crustal thickness, and corresponding gravitational field.	IS: Andrew Cheng, JHU/APL, andy.cheng@jhuapl.edu Co-I: David E. Smith, GSFC, dsmith@tharsis.gsfc.nasa.gov	Radio Science Node (RS) Dick Simpson (rsimpson@magellan.stanford.edu)
Navigation	Bobby Williams, JPL, bobby.williams@jpl.nasa.gov	Navigation and Ancillary Information Node (NAIF) Chuck Acton (charles.h.acton@jpl.nasa.gov)
Engineering	Robert Nelson, JHU/APL, robert.nelson@jhuapl.edu	Navigation and Ancillary Information Node (NAIF) Chuck Acton (charles.h.acton@jpl.nasa.gov)

IS – Instrument Scientist, Co-I listed is the cognizant Co-I.

2.2 Mission Science Background

As described in the Concept Study Report (CSR) and Solomon et al. (2001), MESSENGER is a scientific Discovery mission whose goal is to answer focused science questions using an optimized set of miniaturized instruments: What is the origin of Mercury's high density? What are the composition and structure of its crust? What is the nature of its core? What is Mercury's tectonic history, and has its surface been shaped by volcanism? What are the characteristics of the exosphere and miniature magnetosphere? And what is the nature of the mysterious near-polar deposits? These questions have been formalized in the MESSENGER Concept Study Report (CSR). The questions have been mapped to a set of MESSENGER objectives, which are in turn mapped to measurement objectives (the MESSENGER objectives are captured in Section 2.1.2 of the Program Level Requirements (PLR)).

The science payload for MESSENGER is listed in Table 1. Further information may be found in Gold et al. (2001). The science questions generate measurement objectives for the payload, which flow down to requirements for instrument capabilities and for derived data products, and eventually to science results that provide closure to the mission science objectives (cf. PLR § 2.2). Table 1 also gives, for each instrument, the Co-Investigator(s) cognizant of the measurement objectives and associated derived data and analysis products, and the Instrument Scientist(s) cognizant of the instrument hardware, software, performance, and calibration requirements.

Although Table 1 lists a PDS Node Contact for each of the instruments, Raymond Arvidson of Washington University is the MESSENGER PDS Point of Contact.

2.3 Ground Data System

The MESSENGER Ground Data System (GDS) will convert the raw spacecraft data stream to science data products. The Mission Operations Center (MOC), located at The Johns Hopkins University/Applied Physics Laboratory (JHU/APL), will be responsible for monitoring and commanding the spacecraft and payloads and coordinating real-time mission planning. The MOC receives planetary and spacecraft ephemerides from the Navigation Team, in addition to light time files and tracking requests. The Mission Design and G&C Team supply orbital maneuver information and parameters to the MOC. All payload commanding is generated by the SOC and transferred to the MOC for implementation. The MOC will receive telemetry packets from the Deep Space Network (DSN) and process them through CODMAC (Committee On Data Management And Computation) Level 1 (see Table 2 for CODMAC data Level definitions), providing the CODMAC Level 1 data to the SOC. Navigation data, including spacecraft and planetary ephemerides, and spacecraft pointing data, will be transmitted to the SOC in SPICE format.

The SOC will coordinate all data acquisition, planning, and instrument operations, and will support the MESSENGER Science Team in the processing and analysis of the science data. It will provide easy access to all the data required by the Science Team and the MOC. The SOC will accept and process telemetry, command history, and navigation data through CODMAC Level 1, creating CODMAC Level-2 Experiment Data Records (EDRs), calibration files, and a telemetry archive. The SOC will archive the Level 1 and 2 data with PDS.

The Science Team is responsible for science data processing through CODMAC Levels 3 through 5 and for delivering these products to the SOC in PDS-standard formats including associated documentation, as outlined in each instrument's Software Interface Specification (SIS) documents and the Archive Generation, Validation, and Dissemination Plan (AGVDP). The SOC is responsible for negotiating with the PDS all product formats and delivery of all data products to the PDS. The Science Team will also generate science priorities for flyby encounter activities and in-flight tests, with the science sequence planning coordinated through the SOC.

The roles and responsibilities of the MOC, SOC, and Science Team are discussed in more detail in Section 4.1. A description of the data flow within the MESSENGER project is provided in Section 5.

Table 2. CODMAC/NASA definition of processing levels for science data sets

NASA	CODMAC	Description
Packet data	Raw - Level 1	Telemetry data stream as received at the ground station, with science and engineering data embedded. Referred to in this document as Packetized Data Products (PDRs).
Level 0	Edited - Level 2	Instrument science data (e.g., raw voltages, counts) at full resolution, time ordered, with duplicates and transmission errors removed. Referred to in this document as Experimental Data Records (EDRs).
Level 1A	Calibrated - Level 3	NASA Level 0 data that have been located in space and may have been transformed (e.g., calibrated, rearranged) in a reversible manner and packaged with needed ancillary and auxiliary data (e.g., radiances with the calibration equations applied). Referred to in this document as Calibrated Data Records (CDRs). In some cases, these also qualify as derived data products (DDPs).
Level 1B	Resampled - Level 4	Irreversibly transformed (e.g., resampled, remapped, calibrated) values of the instrument measurements (e.g., radiances, magnetic field strength). Referred to in this document as either derived data products (DDPs) or derived analysis products (DAPs).
Level 1C	Derived - Level 5	NASA Level 1A or 1B data that have been resampled and mapped onto uniform space-time grids. The data are calibrated (i.e., radiometrically corrected) and may have additional corrections applied (e.g., terrain correction). Referred to in this document as derived analysis products (DAPs).
Level 2	Derived - Level 5	Geophysical parameters, generally derived from Level 1 data, and located in space and time commensurate with instrument location, pointing, and sampling. Referred to in this document as derived analysis products (DAPs).
Level 3	Derived - Level 5	Geophysical parameters mapped onto uniform space-time grids. Referred to in this document as derived analysis products (DAPs).
	Ancillary Data – Level 6	Non-science data needed to generate calibrated or resampled data sets and consisting of instrument gains, and offsets, spacecraft positions, target information, pointing information for scan platforms, etc.

The above is based on the National Research Council Committee on Data Management and Computation (CODMAC) data levels.

3. Definitions of Data Deliverables

The science-related data products to be produced during the MESSENGER mission are described in this section, including standard products, engineering and other ancillary products, and documentation that accompanies data sets as they are delivered to the PDS. Table 2 defines numerical processing levels as defined by the National Research Council CODMAC.

3.1 Packetized Data Records (PDRs)

These data records consist of packetized telemetry that is received from the spacecraft with science and engineering data embedded. PDRs have duplications removed and include any ancillary information needed to understand what is contained in a given packet (e.g., instrument data vs. spacecraft health information). These are CODMAC Level-1 data produced by the MOC and delivered to the SOC for production of EDRs. PDRs are not archived to the PDS.

3.2 Standard Products

Standard products are CODMAC Level-2 (See Table 2) and higher science data products. The MESSENGER science data are divided into two categories: Level-2 raw data (referred to as experimental data records or EDRs) and processed data (referred to as reduced data records or RDRs). RDRs are generated from EDRs, and represent either data calibrated to a physical unit such as radiance (Level-3), resampled Level-4 data products, or derived Level-5 data products. RDR standard products are produced primarily by discipline groups on the Science Team (see Sec. 4 Roles and Responsibilities).

The RDRs are subdivided into three groups: calibrated data records (CDRs), derived data products (DDPs), and derived analysis products (DAPs). Tables 3 and 4, taken from the MESSENGER CSR, lists the DDPs and DAPs which the project is responsible for delivering to the PDS to archive. All standard products will be delivered to the Planetary Data System in PDS-compliant format, including PDS labels and documentation. The documentation shall be sufficiently thorough for users to understand the processing history.

Table 3. Derived Data Products (taken from CSR Table D-2-9)

System	Data Product	Team*	Lead	CODMAC Level
MDIS	Catalogued images	GG	Murchie	3,4
GRNS	γ-ray spectra, neutron flux	GC	Boynton	3,4
MAG	**B**-field vectors	AM	Anderson	3,4
MLA	Range profiles, radiometry	GP	Zuber	3,4
MASCS/ UVVS	Limb tangent height spectra	AM	McClintock	3,4
MASCS/ VIRS	Surface reflectance spectra	GC	McClintock	3,4
EPPS	Particle energy vs. composition vs. angle distributions	AM	Gold	3,4
XRS	X-ray spectra	GC	Trombka	3,4
RS	Doppler data, ranging data, occultation times	GP	Smith	3,4

* GG: Geology Group, GC: Geochemistry Group, GP: Geophysics Group, AM: Atmosphere and Magnetosphere Group.

Table 4. Derived Analysis Products (taken from CSR Table D-1-1)

SYSTEM	ANAYLSIS PRODUCT	CODMAC Level
GRNS, XRS	Global element map	5
MDIS, MASCS	Spectral unit map	5
MDIS	Global monochrome map	5
MDIS	Stereo maps	5
MDIS	Multispectral image catalogue	5
MLA	North-hemisphere topography map	5
MLA	Altimetric profiles	5
RS	North-hemisphere gravity model	5
MAG	Multipole internal magnetic field model	5
MAG, EPPS	Time-dependent magnetosphere model	5
MLA, RS	Libration amplitude	5
MLA, RS	RA and DEC of Mercury's rotational pole	5
RS	Spherical harmonic gravity field	5
RS	Low-degree global shape	5
MLA	North-hemisphere topographic profiles	5
MASCS	Exosphere model	5
MASCS, EPPS, GRNS, XRS	Volatile species and sources	5

3.2.1 Experimental Data Records

Raw data or EDRs consist of unprocessed instrument-count data including a description of the observation geometry (boresight, spacecraft, and target). In those cases where on-board compression has been applied, the EDRs contain the unmodified compressed instrument data as downlinked to the SOC through the Deep Space Network (DSN). Compressed and decompressed versions of these EDRs will be delivered to the PDS as CODMAC Level-2 data. Decompressed EDRs will be supplied to the Science Team by the SOC for science analysis purposes. Calibrated Data Records, discussed in the following section, are EDRs which have been decompressed and radiometrically calibrated and are CODMAC Level-3 archive products. Each instrument EDR is formatted to include standard PDS labels (instrument count data are otherwise unprocessed). To make full scientific utilization of the archived EDR data, processing such as decompression, radiometric calibration, and geometric rectification may be necessary. A brief description of each instrument's EDR follows. Detailed descriptions can be found in each instrument's SIS document.

MDIS
Each camera observation results in one to five image products processed on board the spacecraft. The image product may contain the entire image frame or up to five sub-frames. All image products are compressed and stored on the Solid State Recorder (SSR) for downlink to the DSN and then to the SOC. Each image product is stored as an array of lines (rows) and samples (columns) where the array values correspond to raw instrument counts (data numbers, DNs).

GRS
When a gamma ray or cosmic ray interacts with the Ge semiconductor detector, a charge is generated. The amount of charge is proportional to the energy deposited. When a gamma ray or cosmic ray interacts with the borated plastic scintillator shield surrounding the bottom and sides of the Ge detector, a light pulse is generated that is converted to a voltage pulse by a photomultiplier. The pulse magnitude is proportional to the energy deposited. The amount of charge is measured and then converted into the

appropriate channel number, which is proportional to energy. Each GRS observation results in three spectra. The three spectra are described as: (1) all interactions in the primary Ge detector, the raw Ge spectrum; (2) all interactions in the plastic shield, the plastic spectrum; (3) all interactions in the primary Ge detector that are not in coincidence with an interaction in the plastic shield, the Ge anticoincidence spectrum. The first and third spectra are binned into 16384 channels, and the second spectrum is binned into 1024 channels. The distribution of energy deposition as a function of energy (channel number) is recorded over a commanded integration time period. Each EDR is a histogram of the number of events in each channel over the integration period and is designated as a single spectrum.

NS

The MESSENGER NS EDRs consist of five spectra plus event-mode data. These EDRs are generated as follows. The MESSENGER NS consists of a sandwich of three scintillators that are optically decoupled from each other. The first and third scintillators are lithium-glass scintillators, which respond to a combination of thermal and epithermal neutrons that span the range between 0 eV and about 1 keV. Each of these scintillators generates a neutron spectrum (or histogram). When a thermal or epithermal neutron interacts with one of these scintillators a charge is generated. The charge is converted into one of 32 channels, which are correlated to energy. Over a commanded integration time period the distribution of events (neutron encounters) as a function of energy (channel number) is recorded. The result is a histogram of the number of events in each channel accumulated over the integration period, which is designated as a single neutron spectrum. Two such spectra are produced, one by each lithium-glass scintillator.

The center scintillator is a borated plastic (BP) scintillator. Time-correlated events in the BP scintillator provide a measure of the flux of fast neutrons (0.5 MeV < E < 7 MeV). These events are defined by a time-correlated pair of interactions in the BP scintillator. The first interaction corresponds to a neutron that loses all of its sensible energy in the BP scintillator, and the second interaction corresponds to the energy released by the $^{10}B(n,\alpha)^{7}Li$ reaction. The signature of the time-correlated events includes the pulse height (correlated to energy) of the first interaction (called a prompt energy, E_p), the pulse height that corresponds to the Q-value of the $^{10}B(n,\alpha)^{7}Li$ reaction (called the capture energy, E_c), and the time between first and second interactions (or Time To Second Pulse, TTSP). When a fast neutron interacts with the BP scintillator a charge is generated corresponding to E_p. The charge is converted into one of 64 channels, which are correlated to energy. Over a commanded integration time period the distribution of E_p events as a function of energy (channel number) is recorded. The result is a histogram of the number of E_p events in each channel accumulated over the integration period, which is designated as a single neutron spectrum. The event-mode data (E_p, E_c, and TTSP) are also converted into histograms. Over the integration time period the number of events with a given TTSP are counted. The results are two histograms, or spectra. The first histogram is the number of time-correlated events as a function of TTSP for TTSP values ranging from 0 to 0.4 μs. The second histogram is the number of time-correlated events as a function of TTSP for TTSP values ranging from 0.4 μs to 25.6 μs. In addition to the five spectra described above, the NS EDRs include a precommanded subset of the event-mode data (E_p, E_c, and TTSP values).

XRS

Each XRS observation results in four X-ray spectra. When an X-ray interacts with one of the four detectors, a charge or voltage pulse is generated. This signal is converted into one of 2^8 (256) channels, which are correlated to energy. Over a commanded integration time period the distribution of events (X-ray encounters) as a function of energy (channel number) is recorded. The EDRs are the number of events in each channel of the four detectors accumulated over the integration period. The result is four 256-channel histograms, each of which is designated as a single X-ray spectrum.

MASCS/VIRS

The VIRS portion of the MASCS instrument measures surface reflectance in the wavelength range 0.3 to 1.45 μm. VIRS detectors collect photons from the MASCS telescope. A flat field, concave holographic grating disperses and images the fiber aperture onto two linear array detectors. Located near the spectrograph focal plane is a dichroic beam splitter, which separates visible and infrared wavelengths before they are imaged onto the two detectors. The detectors consist of a silicon 512-element array covering the wavelength range 300-1050 nm (using ~320 pixels) and an Indium Gallium Arsenide (InGaAs) 256-element detector covering 850-1450 nm (using all pixels). The spectral bandpass is approximately 5 nm over the entire wavelength range. Photons incident on the detectors generate electrons, which are counted and converted to DN using an electron to DN analog-to-digital conversion factor. Both detectors are digitized to 16 bits and are stored as discrete spatial measurements onboard the SSR in compressed format (lossy and lossless options) for transmission to Earth. A VIRS EDR is an array comprising a single spectrum with associated temperature monitor data and instrument telemetry. Spectra can have acquisition times ranging from 50 ms to several seconds. Nominal acquisition time is 1 s/spectrum. VIRS EDRs will thus consist of two sets (one for each detector) of discrete spatial measurements totaling 576 elements using 16-bit words per element.

MASCS/UVVS

The UVVS portion of the MASCS instrument consists of three photo-multiplier tube (PMT) detectors sensitive across the wavelength range (115 to 600 nm) with a spectral resolution of ~ 1 nm. The Far UV tube is for 115-190 nm light in 0.5-nm steps (2nd order), the Mid UV tube is for wavelengths 160-320 nm in 1-nm steps, and the Vis tube is 250-600 nm in 1-nm steps. Light is collected by a telescope and fed to the spectrometer via an entrance slit. The grating disperses the light as a function of wavelength and, as the grating is scanned, light over a specified wavelength interval falls on one of three exit slits. The exit slits are spatially positioned so that light from each of the three wavelength ranges given above falls on one of the exit slits. Each exit slit leads to one of the PMTs, thus allowing each PMT to count over its specified wavelength range. The PMTs operate in pulse-counting mode and collect photons for a specified integration time. Incoming photons to a PMT hit the photocathode and generate electrons, which are directed toward dynode strings where they multiply. At the end of the tube a pulse amplifier discriminator (PAD) amplifies the electrical signal received and compares against a threshold value to determine whether to send out a count. A UVVS atmospheric profile EDR is a series of accumulated counts at different grating positions. The grating position and integration time are determined by instrument command. The resulting spectra, which may have variable length, are stored as single line arrays of values that correspond to counts per wavelength. UVVS EDRs will thus consist of three sets (one for each detector) of discrete spatial measurements across their respective wavelengths.

EPPS/EPS

EPS observes energetic charged ions and electrons and discriminates them by energy, angle of arrival, and mass species (electrons and ion mass composition). The sample space may be represented as a 3-dimensional Cartesian coordinate system with one axis representing energy, a second axis representing species (electrons and ion mass composition), and the third axis representing angle of arrival (derived by determining which of six detectors was stimulated by the particle). The mass axis includes positions where mass is not determined cleanly. The several hundred data channels in the EDR consist of the rates (in counts per time accumulation) of detected charged particles that occupy several hundred boxes defined within the 3-dimensional sample space. At any one time, different groupings of boxes are sampled with different accumulation times. At any one time, two separate and overlapping groupings of channels may be sampled, each with their own set of accumulation times, representing high- and medium- priority data. Channel accumulations times range from ~300 s to ~0.5 s depending on orbital position. All channel rates are compressed to 10 bits with a log compression scheme. A separate data stream consists of full pulse-height analysis data (PHA) for each of a small subset of individual particles that are detected. The properties of each captured particle are represented in 48-bit words with full PHA information available for energy and particle velocity, yielding high-resolution energy and mass species discrimination.

EPPS/FIPS

FIPS also observes charged ions (not electrons) but over a different range of energies. The sample space for FIPS has one more dimension than does EPS because FIPS performs angle sampling in 2 dimensions rather than just one. The sample space consists of: energy/charge, mass/charge, angle_x, and angle_y. The data channels again consist of the particles per accumulation period that occupy various boxes within the 4-dimensional sample space. Again, different groupings of channels are sampled with various accumulation periods, and two different groupings of channels may be sampled simultaneously, representing high- and medium-priority data. All channel rates are compressed to 8 or 10 bits using a log compression scheme. Again, a separate data stream consists of full PHA information (28 bits) about a small subset of the individual particles that are detected. In the case of FIPS, the PHA data yield high-resolution information concerning the mass species distributions and the angles of arrival.

MAG

The magnetometer records the vector (X, Y and Z axes) magnetic field at the location of the sensor at the tip of the 3.6-meter-long magnetometer boom. The instrument samples internally at 20 samples per second and depending on science objectives and telemetry availability will be commanded to provide output for telemetry at selected rates of 0.01/s, 0.02/s, 0.05/s, 0.1/s, 0.2/s, 0.5/s, 1/s, 2/s, 5/s, 10/s, and 20/s. The nominal rate in orbit is expected to be 1/s. All three axes are output for telemetry at the same rate. The instrument is equipped with two sensitivity ranges, ±65,536 nT (2 nT least significant bit, LSB) and ±1024 nT (0.03 nT LSB), appropriate for pre-launch testing in Earth's field and science observations at Mercury, respectively. The low sensitivity range also provides added dynamic range in case unexpectedly strong crustal fields are present at Mercury.

The MAG EDRs consist of time-ordered series of counts of the X, Y, and Z components, and one field-fluctuation measurement channel (AC level). The AC level is the average absolute value of the 1-10 Hz-filtered magnetic field data. It is a log-compressed 8-bit value (4-bit exponent, 4-bit mantissa) and is also referred to as 'logAC'. Only one axis, selectable by command, is used to evaluate the fluctuation level. The AC level is reported at most once every second. In rates 2/s, 5/s, 10/s, and 20/s the AC level is reported once every second. At lower output rates, the AC level is reported at the commanded output rate.

Three types of MAG EDRs are produced: low-rate housekeeping (MAG-LHK2), standard science data (MAG-SSD2), and burst data (MAG-BST2), where the integer at the end of the data type denotes data level. The EDRs for each type are self contained, independent records.

The MAG-LHK2 records provide low volume, complete orbital coverage of health and safety data and low-time-resolution (50 s, 500 s, or 2000 s between readings) magnetic field and fluctuation level readings. It is designed for daily downlink from the spacecraft to monitor instrument health and provide full-orbit coarse-time-resolution data coverage for mission planning and data survey purposes. On-orbit low-rate housekeeping mode (LHK) will be operated at 50-s sampling between magnetic field samples. During cruise LHK will be operated at 500 s or 2000 s between magnetic field samples. MAG-LHK2 data are uncompressed. Each MAG-LHK2 record consists of a header that includes a start time tag, LHK sample rate, instrument range, primary health and safety data for MAG (electronics and probe temperatures and electronics current), instrument status flags and 10 XYZ field samples, 10 AC levels, and 10 corresponding delta-time tags providing 0.05-s time knowledge relative to the header time tag. Sequential MAG-LHK2 records will comprise a continuous time record. Records with fewer than 10 samples can occur if the instrument is commanded to or autonomously invokes a terminate-LHK packet command. In case of packet termination, no interruption of continuity occurs since the subsequent new LHK packet picks up the time sequence.

The MAG-SSD2 record provides the primary science MAG data and consists of XYZ samples and AC level values at the commanded sample rate. The standard science data (SSD)will be used for detailed science analysis of Mercury's intrinsic magnetic field and of its magnetospheric configuration and dynamics. Each MAG-SSD2 record consists of a header that includes a time tag providing 0.05-s precision, instrument range, sample rate, compression flag (ON/OFF), compression bit length for each axis (XYZ), and 200 XYZ samples together with 200 or fewer AC level samples (see above). The first XYZ sample is uncompressed, and the remaining samples are compressed as differences from the preceding sample using the bit length indicated in the header. Compression of magnetic field values in SSD records may be commanded on or off. Typically compression will be used. Sequential MAG-SSD2 records will comprise a continuous time record. Records with fewer than 200 samples can occur if the instrument is commanded to or autonomously invokes a terminate-SSD packet command. In case of packet termination, no interruption of continuity occurs since the subsequent new SSD packet picks up the time sequence.

The MAG-BST2 records provide snapshots of 20/s vector samples, or 'burst' sampling, over a time span of 8 minutes, a total of 9600 vector samples for each burst interval. The burst data provide information about waves and turbulent phenomena expected to occur at the magnetospheric boundaries and elsewhere in association with pickup processes of volatile species as they are photo-ionized. Each snapshot consists of 15 MAG-BST2 time-contiguous records. Data are recorded at 20/s during a commanded time window when the AC level exceeds a commanded trigger level. The number of bursts to record in each window is also commanded and will typically be 1. MAG-BST2 records consist of a header including instrument range, time tag providing 0.05 s precision, and compression bit length for each axis (XYZ). MAG-BST2 data are always compressed. The body of the data consists of 640 XYZ samples at 20/s sampling rate. The first sample is uncompressed, and the remaining 639 samples are compressed as differences from the preceding sample using the bit length indicated in the header. The

15 MAG-BST2 records comprise a continuous time series spanning the 8-minute burst. Typically one burst period will be recorded every day.

MLA

The MLA is a direct-detection, time-of-flight laser altimeter that determines the range from the spacecraft to the surface of Mercury by measuring the round-trip travel time of laser pulses. The file formats for the downlinked data include a primary header, a secondary header, user data, and instrument status. The EDRs take the form of Flexible Image Transport Standard (FITS) files. The MLA has two operational modes: "standby" and "science". Within the MLA's science mode are three commandable detector threshold modes, five range window modes, and two detector gain modes. In addition to measuring the range to the surface, the MLA also measures the surface reflectance properties at the laser wavelength for nadir geometries (radiometry measurements). The MLA EDRs consist of a table that includes range and radiometry information for each laser return pulse. Each measurement consists of the round-trip time-of-flight in milliseconds, the outgoing and return energy in mJ of each pulse, the threshold setting of the detector, and other measurement-related parameters.

RS

The RS investigation uses the spacecraft coherent X-band telemetry system to obtain range-rate (or Doppler) and range measurements. The former is the radial velocity component of the spacecraft relative to the ground station, and the latter is the distance between the two. Analysis of these data sets yields solutions for the spacecraft orbit relative to the planetary center of mass, after account is taken of propagation effects (through the interplanetary medium and the atmosphere and ionosphere of Earth), the precise location of the ground station, and the motions of the ground station relative to the solar system barycenter due to Earth's orbital and rotational motions, among other factors. More precise and accurate orbital solutions are obtained when the radiometric Doppler and ranging data are combined with additional measurements of the spacecraft position relative to the planet, which for MESSENGER are the altimetric data from MLA. A combined solution for the spacecraft orbit plus the planetary shape, gravity, and rotation state will be obtained from the radiometric and altimetric data.

3.2.2 Calibrated Data Records

CDRs are processed data derived from the EDRs consisting of decompressed and radiometrically calibrated data. Data values are expressed in physical units, such as radiance or reflectance. Ancillary data (CODMAC Level 6), such as compression tables, calibration files, and viewing geometry files (e.g., SPICE kernels), may be needed to construct CDRs. In general, DDPs and DAPs are based on, but separate from, CDRs. Ancillary data used in constructing the CDRs are archived to the PDS commensurately with the CDRs. All CDRs are formatted to include standard PDS labels. A brief description of each instrument's CDRs follows. Detailed descriptions can be found in each instrument's SIS document.

MDIS

To convert MDIS EDRs to CDRs each image product is decompressed using algorithms incorporating the appropriate compression tables and/or compression algorithms. DN values are converted to radiance values using calibration algorithms supplied by the Instrument Scientist based on in-flight and on-ground instrument calibration measurements.

GRS
EDRs from the GRS are histograms of pulse height counts per channel. To convert these EDRs to CDRs, any compression applied to the original measurements prior to storage on the SSR and downlink via the DSN must be removed. Each histogram is decompressed using decompression algorithms incorporating the compression tables and/or compression algorithms from their original construction. Event counts per channel must be converted to a common energy scale so spectra can be summed together. Corrections included are for energy gain, offset, integral non-linearity (INL), and differential non-linearity (DNL). Summed spectra can be analyzed to determine the peak areas of gamma-ray lines. Normally, only the anticoincidence spectrum, which has the best signal-to-noise ratio, will be analyzed for peak areas. The peak areas can be converted to photon fluxes using calibration efficiencies, which include both intrinsic detector efficiency and attenuation through the material surrounding the detector. These efficiencies are derived from both ground-based and in-flight measurements and calculations. The efficiencies and the necessary algorithms to do the conversions are supplied by the Instrument Scientist.

NS
EDRs from the NS are histograms of pulse height counts per channel. To convert these EDRs to CDRs, any compression applied to the original measurements prior to storage on the SSR and downlink via the DSN must be removed. Each histogram is decompressed using decompression algorithms incorporating the compression tables and/or compression algorithms from their original construction. Event counts per channel must be converted to a common energy scale so spectra can be summed together. Corrections included are for energy gain, offset, INL, and DNL. The count rates can be converted to neutron fluxes as a coarse function of energy using background subtraction methods and calibration efficiencies, which include both intrinsic detector efficiency and attenuation through the material surrounding the detector. These efficiencies are derived from both ground-based and in-flight measurements and calculations. The efficiencies and the necessary algorithms to do the conversions are supplied by the Instrument Scientist.

XRS
EDRs from the XRS are histograms of event counts per channel. To convert these EDRs to CDRs any compression applied to the original measurements prior to storage on the SSR and downlink via the DSN must be removed. Each histogram is decompressed using decompression algorithms incorporating the compression tables and/or compression algorithms from their original construction. Event counts per channel are converted to energy spectra using calibration algorithms supplied by the Instrument Scientist based on in-flight and on-ground instrument calibration measurements. The peak areas can be converted to photon fluxes using calibration efficiencies, which include both intrinsic detector efficiency and attenuation through the material surrounding the detector. These efficiencies are derived from both ground-based and in-flight measurements and calculations. The efficiencies and the algorithms to do the conversions are also supplied by the Instrument Scientist.

MASCS/VIRS
All EDR spectra are a vector of values (spectral channels), where the values correspond to data numbers (DNs). VIRS CDRs are produced by first decompressing the EDRs using algorithms incorporating the appropriate compression tables and/or compression algorithms. Raw spectra DNs are converted to

radiance values using calibration algorithms supplied by the Instrument Scientist based on in-flight and on-ground instrument calibration measurements. Radiance values are converted to reflectance using a solar spectrum.

MASCS/UVVS

UVVS CDRs are produced by first decompressing the EDRs (event counts per wavelength on a given PMT) using algorithms incorporating the appropriate compression tables and/or compression algorithms. Counts per wavelength are converted to Rayleighs using calibration algorithms supplied by the Instrument Scientist based on in-flight and on-ground instrument calibration measurements. Two distinct types of CDRs are produced, one corresponding to atmosphere survey observations and the second to atmosphere altitude profile observations.

EPPS/EPS

Calibrated EPS data are generated by reversing the log compression algorithm for each of the rate data channels, converting particles per accumulation period to particles per second, removing non-linearities from the instrument response by performing a so-called “R versus R” correction (“R” represents “rate”; note that the correction for any one channel may involve the use of other channels that are adjacent in energy), and finally converting the resulting linear rates (counts per second) into differential intensities (particles / (cm^2.s.sr.keV) with the use of channel-specific multipliers that involve the so-called geometric factors and channel-energy band passes. Because information about the instrument calibration evolves rapidly, the Calibrated Data Records will initially consist (early in the MESSENGER program) of data channels represented as counts per second. The conversion to intensity will be performed “on the fly” when requested by the user with software developed for that purpose. Calibrated Data Records also consist of the unpacked PHA data (originally 48-bit words). The unpacking processes yields multiple words for each particle event representing detection process (electron, low-energy ion, or high-energy ion process), detector, energy, and time-of-flight. The energy and time-of-flight are converted from PHA numbers to keV and nanoseconds, respectively.

EPPS/FIPS

Calibrated FIPS data are generated by reversing the log compression algorithm for each of the rate data channels, converting particles per accumulation period to particles per second, removing non-linearities from the instrument response by performing a so-called “R versus R” correction (“R” represents “rate”; note that the correction for any one channel may involve the use of other channels that are adjacent in energy), and finally converting the resulting linear rates (counts per second) into differential intensities (particles / (cm^2.s.sr.keV) with the use of channel-specific multipliers that involve the so-called geometric factors and channel-energy band passes. Because information about the instrument calibration evolves rapidly, the Calibrated Data Records will initially consist (early in the MESSENGER program) of data channels represented as counts per second. The conversion to intensity will be performed “on the fly” when requested by the user with software developed for that purpose. Calibrated Data Records also consist of the unpacked PHA data (originally 28-bit words). The unpacking process yields multiple words for each particle event representing energy per charge, time-of-flight, “x-position”, and “y-position”. The time-of-flight, x-position, and y-position are converted from PHA numbers to nanoseconds, centimeters, and centimeters, respectively.

MAG

To obtain CDRs the magnetic field XYZ readings in each of the MAG-EDR types are uncompressed, if necessary, using the information in the EDR headers. Counts, 0000_{16} to $FFFF_{16}$, are converted to signed integers and then multiplied by the pre-launch calibration matrix appropriate for the full-scale magnetic magnitude value range indicated in the EDR header. The matrix includes the scale factor conversion to nanoTesla (nT) units and corrects for small non-orthogonality effects in the sensor to yield orthogonal XYZ magnetic field values in sensor coordinates. This matrix and its inverse are included in Ancillary Data. The header time tag is used to evaluate the time of each magnetic field reading to 0.05-s resolution using the packet time tag and sample rate. No other time corrections are applied (e.g., for instrument latency). Time is expressed in spacecraft event time, e.g. Mission Elapsed Time (MET), or equivalent. Three MAG-CDRs are produced, MAG-LHK3, MAG-SSD3 and MAG-BST3 records, which map one-to-one to their corresponding EDRs. Each record consists of a series of time-tagged vector magnetic field values, up to 10 in each LHK3 record, up to 200 in each SSD3 record, and 640 in each BST3 record.

Two types of intermediate, CODMAC Level-4, records are produced. The first type are assembled time series created by combining all CODMAC Level-3 records starting in a given day to produce one CODMAC Level-4 record per day. All LHK3 records starting on a given day are combined to produce one LHK4 record. Similarly, all SSD3 records starting in a given day are combined to produce one SSD4 record. The BST3 records are combined in a different way. Each set of 15 BST3 records corresponding to a given burst interval is combined into a single BST4 record so that there is one BST4 record for every burst interval. There may be none or more than one BST4 records for a given day. BST4 records are not divided by day boundaries, that is, all BST3 records for a given burst interval are included in a single BST4 even if a day boundary occurs during the burst interval. In addition to combining records into single daily or burst files, any spacecraft magnetic fields derived by post-launch analysis are subtracted from the magnetic field values in all three types of records, LHK4, SSD4 and BST4. Spacecraft magnetic field corrections will be provided as Ancillary Data. The second type of CODMAC Level-4 products are summary electronic-format survey plots of the time series in LHK4, SSD4, and BST4 records.

MLA

The MLA EDRs are records of times of flight measured versus mission elapsed time. The CDRs are derived from the MLA EDRs by applying decompression (where applicable) and calibration algorithms supplied by the Instrument Scientist. The calibration involves converting the range measurement to meters and making corrections for pulsewidth, pulse energy, and their sensitivity to temperature and other instrument and planetary parameters.

RS

The RS EDRs contain two data types: the Doppler shift in Hz versus UTC (universal time) and the Earth-to-spacecraft range versus UTC. CDRs are derived from the RS EDRs by applying decompression (where applicable) and calibration algorithms supplied by the Instrument Scientist. The Doppler shift is measured using the spacecraft coherent transponder, which is phase-locked to the radio signal as received from the Earth. The Doppler shift is used to obtain the range-rate or radial velocity component. The calibration involves converting the Doppler measurements to engineering units by making corrections for atmospheric and interplanetary propagation effects, station location, and other factors.

The range measurement uses the ranging transponder to measure the round trip time-of-flight for a radio signal between the spacecraft and the Earth. Calibration involves corrections for propagation effects, station location, and additional factors.

3.2.3 Derived Data Products

Table 3 lists the derived data products (DDPs) that the MESSENGER project will deliver to the PDS. These DDPs are outlined in the MESSENGER CSR. A brief description of each instrument's DDPs follows. Detailed descriptions can be found in each instrument's SIS document. The ancillary data (Level 6) needed to produce these products are described elsewhere in this section and in section 3.3. It is the responsibility of the Science Team to produce these products and deliver them to the MESSENGER SOC.

MDIS
The DDP for the MDIS cameras are a monochrome and multispectral image catalogue that describes the geometry and camera setting of each MDIS observation. This database will aid users not familiar with the mission to find observations rapidly to meet their scientific goals and is an important value-added product for the entire mission. This catalogue is separate from the EDR and CDR images, and can serve as an observation search tool.

GRS
The DDPs are the elemental compositions derived from the incident photon flux on the detector for each gamma-ray peak. The conversion from photon flux to composition depends on an assumed model composition that in turn is used to derive the neutron leakage fluxes and gamma-ray fluxes. A neutron-photon Monte Carlo code, such as the MCNPX code that is being used by Mars Odyssey (Boynton et al. 2002), calculates the fluxes from the assumed composition. These calculated values are compared with the measured values, and appropriate changes are made to the model and new calculations are made until there is agreement between the two.

NS
Neutron spectra do not have sharp peaks corresponding to energies associated with individual elements but have higher count rates. Use of sophisticated spectral background subtraction algorithms and the "ram/wake" detector concept, along with filter functions derived from neutron transport computations (using codes such as MCNP, Feldman et al. 1995) that improve energy definition for thermal and epithermal neutrons, allow identification of very light elements such as hydrogen and coarse determination of average atomic mass.

XRS
The DDPs are the elemental composition ratios derived from the incident photon flux on the detectors for each X-ray peak in the three planet-looking detectors. Fitting of the three spectra is done simultaneously to develop a self-consistent result. The conversion from photon flux to composition ratios depends on the input solar spectrum derived from the solar monitor. The shape of this spectrum is compared to solar models to determine a solar temperature. The solar temperature is applied to the fitted results from the planet-looking detectors as an energy-dependent normalization.

MASCS/VIRS

VIRS DDPs listed in the MESSENGER CSR are defined as surface radiance spectra. These can be described as a table of validated, interpretable, reducible radiance spectra at given latitudes, longitudes, footprint dimensions and orientations, time markers, and viewing geometries for the entire planet (and a solar reference spectrum). The data set will be a set of data cubes or tables which can be combined to make a "global spectral dataset".

MASCS/UVVS

UVVS DDPs will be tables of atmospheric emission radiance profiles ("limb tangent height spectra") of Mercury as a function of altitude from the surface, location of profile, viewing geometry, time of Mercury day and year, and possibly solar distance and Mercury radial velocity. UVVS spectra have discrete emission lines that identify individual elements.

EPPS/EPS

EPS begins with a 3-dimensional data cube that has the data parsed according to energy, species (electrons and ion mass composition), and angle (look directions). Higher-level data products are derived by (1) converting the angular directional information into geophysically significant coordinates, and (2) reducing the dimensionality of the information by performing various cuts through and summations over portions of the data cube, and performing various weighted integrations over selected regions of the data cube (thereby obtaining "moments"). Derived data products defined to date include: (1) "energy spectra" of various selected species; (2) such distribution "moments" as pressure, density, integral intensity, and integral energy intensity for various selected species; (3) ion mass species distributions over selected ranges of energies, and (4) pitch angle distributions for various species and over selected ranges of energies (pitch angle is the angle with respect to the local magnetic field direction). Generally, derived data products are generated "on the fly" when requested by the user by software developed for that purpose. They are not generated as a matter of course for all of the data.

EPPS/FIPS

FIPS begins with a 4-dimensional data cube that has the data parsed according to energy/charge, mass/charge, and two different angles (look directions). Higher-level data products are derived by (1) converting the angular directional information into geophysically significant coordinates, and (2) reducing the dimensionality of the information by performing various cuts through, and summation over portions of, the data cube, and performing various weighted integrations over selected regions of the data cube (thereby obtaining "moments"). Derived data products defined to date include: (1) mass per charge distributions over selected ranges of energy/charge, (2) "energy spectra" of various selected species; (3) such distribution "moments" as pressure, density, integral intensity, and integral energy intensity for various selected species; (4) pitch angle distributions for various species and over selected ranges of energies; and (5) angle-space images of particle arrival directions (for various mass species and over various ranges of energy/charge) oriented with respect to, and in some cases remapped to, one or more geophysically significant coordinate systems derived with knowledge of the solar wind direction, the local magnetic field direction, and the direction to Mercury.

MAG

The MAG-DDRs consist of vector magnetic field values in physical coordinates together with absolute time (e.g., UTC) and spacecraft position in physical coordinates. The conversion of the vector magnetic field values to physical coordinates includes transformation from MAG sensor coordinates to spacecraft coordinates defined by the attitude sensors (star cameras) in the spacecraft avionics. Transformation to physical coordinates from spacecraft coordinates is performed using SPICE routines, as is evaluation of spacecraft position. Different sets of values corresponding to multiple coordinate systems will be provided: inertial celestial (e.g., J2000), Mercury-centered body-fixed, Mercury-centered magnetospheric, Mercury-centered solar wind, and solar orbital (appropriate for cruise). Detailed definitions of some of these coordinate systems remain to be formulated. Magnetospheric coordinates in particular depend on the orientation of Mercury's magnetic dipole as derived under derived analysis products and will therefore be updated during the mission.

MLA

The MLA DDPs include range profiles and radiometry. Range profiles are the time series of measured ranges. There are two methods for deriving range values. The MLA receiver has three channels with different time constants (10 ns, 60 ns and 270 ns). In the narrowest filter channel there are two threshold levels. The receiver records 4 stops (leading and trailing) if a return pulse triggers this channel. From these values, the range is found by centroiding, and the return energy is found by fitting to a pulse shape. These are the MOLA-type range measurement and the radiometry measurement. The other channels have different, lower threshold values, and the receiver will record up to 10 stops from each of them. Over some window the receiver constructs a histogram from which it picks out the range. This is the second method for determining the range value. Given an orbit solution, planetary shape and rotation solution and pointing information, these can be converted to ranges along a latitude-longitude track. The orbit, shape, rotation, and gravity are all solved simultaneously from the set of range profiles. Radiometry is the surface reflectance measurement at zero phase.

RS

The RS DDPs include the Doppler range-rate data, the ranging data, and radio occultation data (time intervals when signal is lost because the spacecraft passes behind the planet as seen from Earth). These are expressed in engineering units, after calibrations, corrections, resampling, and weighting of data.

3.2.4 Derived Analysis Products

Table 4 lists the derived analysis products (DAPs) that the MESSENGER project will deliver to the PDS. These DAPs are outlined in the MESSENGER CSR. A brief description of each instrument's DAPs follows. Detailed descriptions can be found in each instrument's SIS document. The ancillary data (Level 6) needed to produce these products are described elsewhere in this section and in section 3.3. It is the responsibility of the Science Team to produce these products and deliver them to the MESSENGER SOC.

MDIS

Derived analysis products from the MDIS fall into two broad categories, those produced from images acquired during the flybys and those from the orbital operations. From the flybys products include four quadrature monochrome mosaics (NA camera) with a central resolution of ~1 km/pixel (resolution falls off radially towards the limb), four quadrature 7-color mosaics with a central resolution of ~5 km/pixel, and two 3-color approach and departure movies. During orbital operations systematic mapping will result in a global monochrome basemap at 250 m/pixel, a merged flyby and orbital global color mosaic in seven spectral filters at ~1 km/pixel, local stereo-based digital elevation models, and very-high-resolution (NA camera) local strip mosaics in the northern hemisphere (best resolutions will be on the order of 20 m/pixel).

GRS
Identification of elements and their concentrations covering a wide range of spatial scales are the first-order DAPs. Other products result from gamma-ray spectra that can be summed spatially in many different ways including accumulations over latitude-longitude bins, accumulations over spatial features on the surface, and spatial accumulations over time to map temporal changes. Each of these accumulations can be converted to composition, and then these compositions can be mapped onto the planet with the spatial resolution inherent with the GRS (approximately equal to the altitude).

NS
Identification of hydrogen and its concentration and average atomic mass covering a wide range of spatial scales are the first-order DAPs. Other products result from neutron spectra that can be summed spatially in many different waysincluding accumulations over latitude-longitude bins, accumulations over spatial features on the surface, and spatial accumulations over time to map temporal changes. Each of these accumulations can be converted to coarse “elemental composition”, and then these “elemental compositions” can be mapped onto the planet with the spatial resolution inherent with the NS (approximately equal to the altitude).

XRS
The primary derived analysis products are element identification and composition ratios over as much of the planet’s surface as possible. The spatial resolution of composition maps will vary with the element and counting statistics. Maps as a function of latitude and longitude will be generated where feasible. Compositions of particular regions of interest may also be possible.

MASCS/VIRS
Identification of minerals and their abundances globally, regionally, and at specific locations are the first-order DAPs. Fe-bearing minerals and Ca silicates can be identified through absorption band characterization, TiO_2 from short-wavelength characteristics, and FeO through spectral uniformity. These and other products result from ratioing different spectral channels, tangent finding for slopes, and curve fitting for band parameters. Spatial coverage and resolution will depend on altitude and orbit. The delivered DAP will include interpolated maps of key wavelengths, ratios, and/or spectral absorption band parameters.

MASCS/UVVS
Emission line strengths determine the elemental line-of-sight column abundance of known (H, O, Na, K, Ca) and predicted (S, Si, Mg, Al, OH, Fe, Al) atmospheric constituents. MASCS UVVS is very much a discovery instrument, so specific DAPs will depend on what is actually detected. Possible DAPs include a general Mercury exosphere model and identification of volatile species and sources (with geographical, altitudinal, and temporal dependences).

EPPS/EPS

EPS derived analysis products are products that involve multiple data sets (for instance EPS+FIPS+MAG) and/or that require hands-on, event-by-event analysis of the data. New derived analysis products will be produced as the analysis of the data proceeds. Among those DAPs defined to date are: (1) plasma beta parameter involving EPS and FIPS moments with normalization by magnetic field pressure values; (2) other plasma moments that involve combining the weighted integral moments performed using EPS and FIPS data; (3) analytic functional spectral fits that combine many data channels in a procedure that allows for improved discrimination of different mass species and improved spectral characterization over a broader range of energies; (4) phase space densities of charged particles, where the conversion from intensity to phase space densities involves the use of Mercury magnetic field models derived with the help of the MAG sensor; (5) tables and statistical maps of magnetospheric regions that includelocations of various magnetospheric boundaries, locations of regions of magnetic connectivity to Mercury; spatial distributions of various hot plasma moments,spatial distributions hot plasma composition, and regions of bursts and other dynamical activity.

EPPS/FIPS

FIPS derived analysis products are products that involve multiple data sets (for instance FIPS+EPS+MAG) and/or that require hands-on, event-by-event analysis of the data. New derived analysis products will be produced as the analysis of the data proceeds. Among those DAPs defined to date are: (1) plasma beta parameter involving FIPS and EPS moments with normalization by magnetic field pressure values; (2) other plasma moments that involve combining the weighted integral moments performed using FIPS and EPS data; (3) analytic functional spectral fits that combine together many data channels in a procedure that allows for improved discrimination of different mass species and improved spectral characterization over a broader range of energies; (4) phase space densities of charged particles, where the conversion from intensity to phase space densities involves the use of Mercury magnetic field models derived with the help of the MAG sensor; (5) two-dimensional particle images with overlaying predictions of particle arrival directions based on the pick-up and other processes; (6) tables and statistical maps of magnetospheric regions that include locations of various magnetospheric boundaries, spatial distributions of various cold and hot plasma moments, spatial distributions of plasma composition, and regions of bursts and other dynamical activity.

MAG

MAG derived analysis products are produced in two basic areas: planetary magnetic field and magnetosphere. The planetary magnetic field MAG-DAPs will consist of a dipole model , a multipole model, and a longitude/latitude map of departures from the model field over latitudes northward of approximately 45°N.

The dipole representation of Mercury's magnetic field will include magnitude and orientation and will initially assume a planet-centered position. The dipole representation will be constructed from magnetic field observations obtained within the Mercury magnetosphere and will be updated approximately monthly as more data are acquired. The dipole model will include an eccentricity when the uncertainty in the offset dipole is less than approximately 0.1 planetary radii, estimated to be possible approximately three months after orbit insertion. The dipole model will be used to organize magnetospheric observations in magnetic coordinates.

In addition to the dipole model, a multipole model, including terms at least through the quadrupole moment, will be constructed after three months of data have been obtained and repeated approximately every three months. A fit including octopole terms will also be attempted. The multipole representation will be constructed from magnetic field observations obtained within the Mercury magnetosphere corrected for contributions of the magnetospheric current systems. Restriction of data to particularly quiet passes may be required. The reliability of higher order terms will depend on the accuracy of the Mercury magnetosphere model. Present estimates indicate that perhaps meaningful quadrupole terms may be obtained but that octopole terms are likely to have large uncertainties.

In the northern hemisphere data will be obtained at altitudes down to 200 km. These data provide an opportunity to specify the level of higher-order structure in the magnetic field in this region. Six months into the orbital phase of the mission, the departure of measurements (with the external field removed) from the dipole field model will be computed in body-fixed coordinates. A map of these residuals will be constructed by averaging the residuals over bins approximately 6° in latitude bins by ~100 to 200 km in longitude. We expect the map to cover latitudes northward of approximately 45°N.

MAG-DAPs of primary relevance to magnetospheric studies will consist of magnetopause and shock-crossing identifications and residual magnetic fields after removal of the planetary magnetic field. EPPS data will be used to confirm the crossings identified in the magnetic field data. The residual magnetic fields will be used to develop a semi-empirical magnetospheric model. As this model is refined it will be used to improve the corrections applied in analysis of the intrinsic magnetic field. Burst observations will be processed for spectral signatures of heavy ions and wave and turbulence processes in various areas of the magnetosphere. Analysis of these data will be event-,driven and will be performed in close association with EPPS observations as will analysis of highly time-dependent signatures in the magnetic field. The results of these analyses will be incorporated in the development of a Mercury magnetospheric model.

MLA

The DAPs produced from the MLA observations include northern hemisphere topographic profiles and map, altimetric profiles, a determination of the libration amplitude, and a measure of the right ascension (RA) and declination (DEC) of Mercury's rotational pole. All of these DAPs fall out of the simultaneous solution for orbit, shape, rotation, and gravity. The primary data product will be a record of the altimetry measurement presented as a measurement of the radius of the planet at a specified location (latitude and longitude). This will be generally known as the altimeter profile product. The altimeter profile product will have an along-track resolution of 0.8-1 km. This product is developed by first determining the position of the spacecraft from the tracking data, using the spacecraft quaternion information to derive the location of the laser spot on the surface of the planet, and then deriving the radius of the planet at the spot location from a knowledge of the radius to the satellite and the altimeter range measurement to the surface. The radius measurements will be reduced to topography (elevation referenced to a geoid) versus latitude and longitude in the Northern hemisphere. A gridded topography map of the northern hemisphere will also be produced from the altimeter profiles. The libration amplitude and phase is determined from a combination of the altimetry data and the tracking data, to find the lowest order longitudinal harmonics (through order 4) referenced to the planetary center of mass. Both datasets can independently provide a measure of the libration, and the tracking data provide the measurement of the obliquity, but a simultaneous solution from both the tracking and the altimetry provides the strongest solution for all parameters.

RS

The RS DAPs include a northern hemisphere gravity model and spherical harmonic models of the gravity field and global shape. In addition, occultation radii are determined at specific latitudes and longitudes. The gravity and shape are determined from a combined solution for the spacecraft orbit and the planetary shape, gravity, and rotation state, as mentioned above. A spherical harmonic gravity model to degree and order 16 will be recovered, with a resolution of about 400 km in the northern hemisphere and about 1500 km in the southern hemisphere. A spherical harmonic shape model, likewise to degree and order 16, will be determined from the gravity and MLA altimetry data. The times of loss and acquisition of radio signals in the occultation data will be reduced to occultation radii versus latitude and longitude, using the spacecraft orbit, the planetary rotation state, and knowledge of the Earth viewing geometry.

3.3 Ancillary Data

Level 6 ancillary data include data needed to produce the MESSENGER science products, such as calibration and compression algorithms and tables, as well as engineering products.

3.3.1 Calibration Data

Each instrument will be obtaining pre-flight and in-flight calibration measurements. These calibration measurements will characterize the performance and capabilities of each instrument and will be used to derive the calibration algorithms and tables needed to interpret the scientific measurements made during the mission. Details of the calibration data expected from each instrument, in addition to calibration data archive guidelines, can be found in their individual Calibration Plans. The schedule for archive delivery of calibration data is described in section 6 of this document.

3.3.2 Navigation Data

Engineering data, while not strictly science data, can be used to aid the interpretation and processing of science data and as such will be archived as Level 6 ancillary data. Some engineering products, predominately SPICE files, are necessary for producing the higher-level science products, such as the DDPs and DAPs.

SPICE is an acronym used to describe a suite of elemental ancillary data sets, often called kernels:

- S Spacecraft ephemeris, with files containing spacecraft location as a function of time
- P Planetary/satellite ephemerides and associated target-body physical and cartographic constants
- I Instrument information, including mounting alignment and field-of-view size/shape/orientation
- C Camera orientation of a spacecraft's primary coordinate systems and possibly angular rates
- E Event information, including nominal sequences, real-time commanding, unscheduled events, and experimenter's notebook comments.

Flight operations teams will generate most SPICE kernels with some instrument information and sequence data obtained from instrument teams. Where appropriate, there will be both predicted and reconstructed SPICE files. Reconstructed SPICE kernels will typically be generated within 3 weeks of data acquisition and made available to instrument teams. SPICE kernels will be used together with a toolkit of software modules (to be supplied through the PDS by JPL's Navigation and Ancillary Information Facility) at investigator institutions to generate the derived ancillary data needed to help plan observations and to process the returned data. Table 5 summarizes the SPICE data expected for this mission.

Table 5. SPICE Data Summary

Data File	Originator	Type of Information
Planetary ephemeris	NAIF	Planetary position vs. time
MOC S/C ephemeris – short term predicts	NAV	Predicted S/C position vs. time
MD S/C ephemeris – long term predicts	NAV/MD	Predicted S/C position vs. time
SOC S/C ephemeris - actual	NAV	S/C position vs. time
S/C attitude – short term predicts	MOC - Statesim	Predicted S/C quaternians
S/C attitude – long term predicts	SOC	Predicted S/C quaternians
Instrument pointing	SOC w/ NAIF support	MDIS boresight pointing
Instrument field of view	SOC w/ NAIF support	MDIS FOV definitions
Frame kernels	SOC w/ NAIF support	MDIS frame definitions
MET/UTC correlation: coarse	MOC	MET to UTC conversion
MET/UTC correlation: fine	MOC	MET to UTC conversion

3.3.3 Engineering Products

Engineering products are a subset of Ancillary Products used in the interpretation of instrument data. They may include such information as instrument voltages, currents, and temperatures. The spacecraft health status may also be included as an engineering product.

3.4 Documentation

Documentation of data acquisition and processing histories is crucial to successful long-term use of project data and will contain information delineating why data sets were acquired, including whether they were part of a coordinated sequence. Information on spacecraft events that affected the sequences and data products will also be included. The actual (as opposed to predicted) SPICE files will be transferred to a long-term archive along with raw and reduced data.

Information needed to understand fully EDRs, SPICE files, and reduced data will also be generated for long-term use of MESSENGER project data. Documents, their providers, and due dates will include:

- For each instrument, a calibration requirements document (Instrument Scientists, Jan. 2003)
- Instrument description and pre-launch calibration reports (Lead Engineers and Instrument Scientists, launch + 30 days)

- In-flight calibration reports (Instrument Scientists and Lead Engineers, as appropriate)
- Descriptions of data products from particular instruments and how they were generated (such as contained in the instrument SIS documents)
- Instrument-specific sequence of events (SOC, maintained continuously)

Documentation to be provided by the project will include a Mission Operations Report, stipulating how the mission plan was actually carried out.

3.5 Software

It is expected that standard data products delivered by the PI or science team should be in a format that is accessible by other users. If the products cannot be accessed using commonly available software tools, then the products should be accompanied by software, detailed algorithms, or descriptions that allow a user to access the data.

4. Roles and Responsibilities

This section summarizes the roles and responsibilities of the organizations (and the key personnel within these organizations) who are involved in the generation, validation, transfer, and dissemination of MESSENGER data to both the scientific community and the general public. These organizations include the MESSENGER project, the PDS, The Johns Hopkins University Applied Physics Laboratory (JHU/APL), the Carnegie Institution of Washington (CIW), and Applied Coherent Technologies (ACT). The MESSENGER project, through its Science Team and SOC, is responsible for archive generation and validation. The PDS is responsible for ensuring that the archive meets PDS standards (including peer review of the data), advising the MESSENGER project and its Science Team on archive-related issues, maintaining active archives of MESSENGER products for access by the science community, and interfacing with the National Space Science Data Center (NSSDC) for long-term archiving of the MESSENGER data. Table 6 summarizes the responsibilities for producing and archiving the standard products, ancillary data, and documentation.

Table 6. Product responsibility

Product	Level	Producer	Mission Source to PDS
Raw instrument telemetry	1	MOC	SOC
Cleaned & merged instrument telemetry	1	MOC	SOC
STANDARD PRODUCTS			
Individual instrument EDRs	2	SOC	SOC
Individual instrument CDRs	3	SOC	SOC
Catalogued images	3,4	GG	SOC
γ-ray spectra, neutron flux	3,4	GC	SOC
B-field vectors	3,4	AM	SOC
Range profiles, radiometry	3,4	GP	SOC
Limb tangent height spectra	3,4	AM	SOC
Surface reflectance spectra	3,4	GC	SOC
Particle energy vs. composition vs. angle distributions	3,4	AM	SOC
X-ray spectra	3,4	GC	SOC
Doppler data, ranging data, occultation times	3,4	GP	SOC
Global element map	5	GC	SOC
Spectral unit map	5	GC	SOC
Global monochrome map	5	GG	SOC
Stereo maps	5	GG	SOC
Multispectral image catalogue	5	GG	SOC
North-hemisphere topography map	5	GP	SOC
Altimetric profiles	5	GP	SOC
North-hemisphere gravity model	5	GP	SOC
Multipole internal magnetic field model	5	AM	SOC
Time-dependent magnetosphere model	5	AM	SOC
Libration amplitude	5	GP	SOC
RA and DEC of Mercury's rotational pole	5	GP	SOC
Spherical harmonic gravity field	5	GP	SOC
Low-degree global shape	5	GP	SOC
North-hemisphere topographic profiles	5	GP	SOC
Exosphere model	5	AM	SOC
Volatile species and sources	5	AM	SOC
ANCILLARY DATA			
SPICE	6	See Table 5, Originator	SOC
Command history	6	MOC	SOC
Calibration files, tables, algorithms	6	ST	SOC
Compression files, tables, algorithms	6	ST, MOC	SOC
DOCUMENTATION			
Calibration Description Papers	N/A	ST	SOC
Instrument Description Papers	N/A	ST	SOC
Data Product Descriptions	N/A	ST	SOC
Instrument-specific sequence of events	N/A	SOC	SOC

* GG: Geology Group, GC: Geochemistry Group, GP: Geophysics Group, AM: Atmosphere and Magnetosphere Group, ST: Science Team, SOC: Science Operations Center, MOC: Mission Operations Center.

4.1 MESSENGER Project

The MESSENGER project is responsible for the production and delivery to PDS of documented archives of raw and reduced data records (EDRs and RDRs) that meet PDS standards and for release of data to the general public. The key personnel and sub-groups within the MESSENGER project involved with the production and delivery of archived data include the Principal Investigator (PI), the Project Scientist (PS), the Instrument Scientists, the Science Team, the cognizant Co-Investigators (cognizant Co-Is, who are also members of the Science Team), the SOC, and the Data Archive Working Group (DAWG).

Principal Investigator
The MESSENGER PI is responsible for primary interactions with NASA Headquarters, ensuring that Headquarters personnel are aware of information releases before they occur, and for providing feedback from Headquarters to other members of the MESSENGER project. It is the responsibility of the PI to formulate the policies and implementation plans concerning the release of information and interactions with the general public and the press. It is the responsibility of the PI or his designate to review all materials prior to release to the general public and the press to insure compliance with NASA Headquarters and MESSENGER project policies.

Project Scientist
The MESSENGER PS provides oversight to MESSENGER mission science planning, data acquisition, data validation, and the generation and validation of the data archives. Working with the PS (and his designates) the science planning, data acquisition, data validation, and data archive generation functions will be accomplished via the SOC, with the assistance of the Science Team, the Instrument Scientists, and the cognizant Co-Is.

The PS has primary responsibility for scientific oversight of routine operations (such as science planning, data acquisition, and data validation) and for ensuring that scientific findings are made available to the media. Specifically, the PS or his/her designates, will:

- lead preparation of the plan for data generation, archiving, and public release
- ensure delivery of press release materials to NASA Headquarters that allow for sufficient lead time (typically one week)
- coordinate preparation and Web release of summary and public relations data products by the Instrument Scientists (described below)
- coordinate the preparation of audiovisual materials (press releases, interviews, press conference scripts, video file productions, etc.) with the APL media relations representative
- identify themes or subjects for public release materials
- enforce graphical standards for all publicly released data products.

Instrument Scientists
Each Instrument Scientist is a member of the SOC's Science Planning Group (SPG) and is responsible for the daily planning of the data acquisition that will enable the MESSENGER project to meet its science objectives. Working with the tools provided by the SOC (and developed with guidance from the

Instrument Scientists), the Instrument Scientists are responsible for data acquisition and data validation. In conjunction with ACT, the prime MESSENGER project sub-contractor for the SOC, the Instrument Scientist is responsible for providing calibration algorithms for producing all CDRs. Instrument Scientists and cognizant Science Team Co-Investigators are responsible for working with PDS and ACT personnel on planning, generating, and validating archives from their instruments.

Each MESSENGER Instrument Scientist is responsible for following the PI's policies and implementation plans concerning the release of information and interactions with the public and press. He/she is also responsible for providing the MESSENGER PI with information necessary to support PI interactions with NASA Headquarters.

In summary, the Instrument Scientist will:

- develop instrument performance and calibration requirements
- lead the analysis of calibration data
- develop data validation and calibration algorithms
- apply the data validation and calibration algorithms to create the Level-2 or greater data given in Table 2, either (a) directly with delivery to the SOC of calibrated data that meet agreed-upon PDS standards, or (b) by supplying the SOC with agreed-upon algorithms to be applied in automated fashion in pipeline format
- oversee the scientific validity of data products archived by the SOC
- participate in and oversee the generation of flight instrument command sequences
- provide science validation for the generated command sequences
- generate for public release, via the Web, summary products showing the status of instrument data in a format appropriate to the instrument
- generate for public release, via the Web, selected products suitable for reproduction in print and video forms, with separate captions written for general and technical audiences.

Science Team

The Science Team is organized into four broad disciplinary groups with distinct but complementary interests. The Geology Group (interested in the MDIS, MLA, and MASCS/VIRS observations), the Geochemistry Group (interested in the GRNS, XRS, MDIS, and MASCS/VIRS observations), the Geophysics Group (interested in the MLA, MAG, and RS observations), and the Atmosphere and Magnetosphere Group (interested in the EPPS, MAG, and MASCS/UVVS observations).

The Science Team, through its disciplinary groups, has the overall responsibility for setting observing priorities for the spacecraft instruments in order to meet the science goals of the MESSENGER project. The data from these observations constitute the raw science data, the fundamental element of the archive. In addition, the Science Team is responsible for generating all DDPs and DAPs (listed in Tables 3 and 4) that will be archived to the PDS for dissemination to the science community. The Science Team is also responsible for providing observation quality assessment criteria to the SPG.

Cognizant Co-Investigators

Within the Science Team there are cognizant Co-Is who are associated with each instrument on board the MESSENGER spacecraft. The cognizant Co-Is will lead the Science Team effort for producing these data products and as members of the MESSENGER SOC are responsible for delivery of these products from the Science Team to the MESSENGER SOC. The cognizant Co-Is are responsible for clearing all liens generated by the PDS review process on products produced by the Science Team groups interested in their instrument's data set.

Cognizant Co-Is, as members of both the Science Team and the SOC, are responsible for delivering to the SOC from the Science Team the RDRs produced by the MESSENGER project. They are responsible for:

- review of instrument performance and calibration requirements
- participation in analysis of calibration data
- review of data validation and calibration algorithms and their application
- coordination of the generation of higher-order (CODMAC Level-3 and higher) data products given in Tables 3 and 4, and coordination of their delivery to the SOC in agreed-upon formats that meet PDS standards
- review and participation in the generation of flight instrument command sequences
- science validation for the generated command sequences
- clearing all liens generated by the PDS review process on products produced by the Science Team groups interested in their instrument's data set.

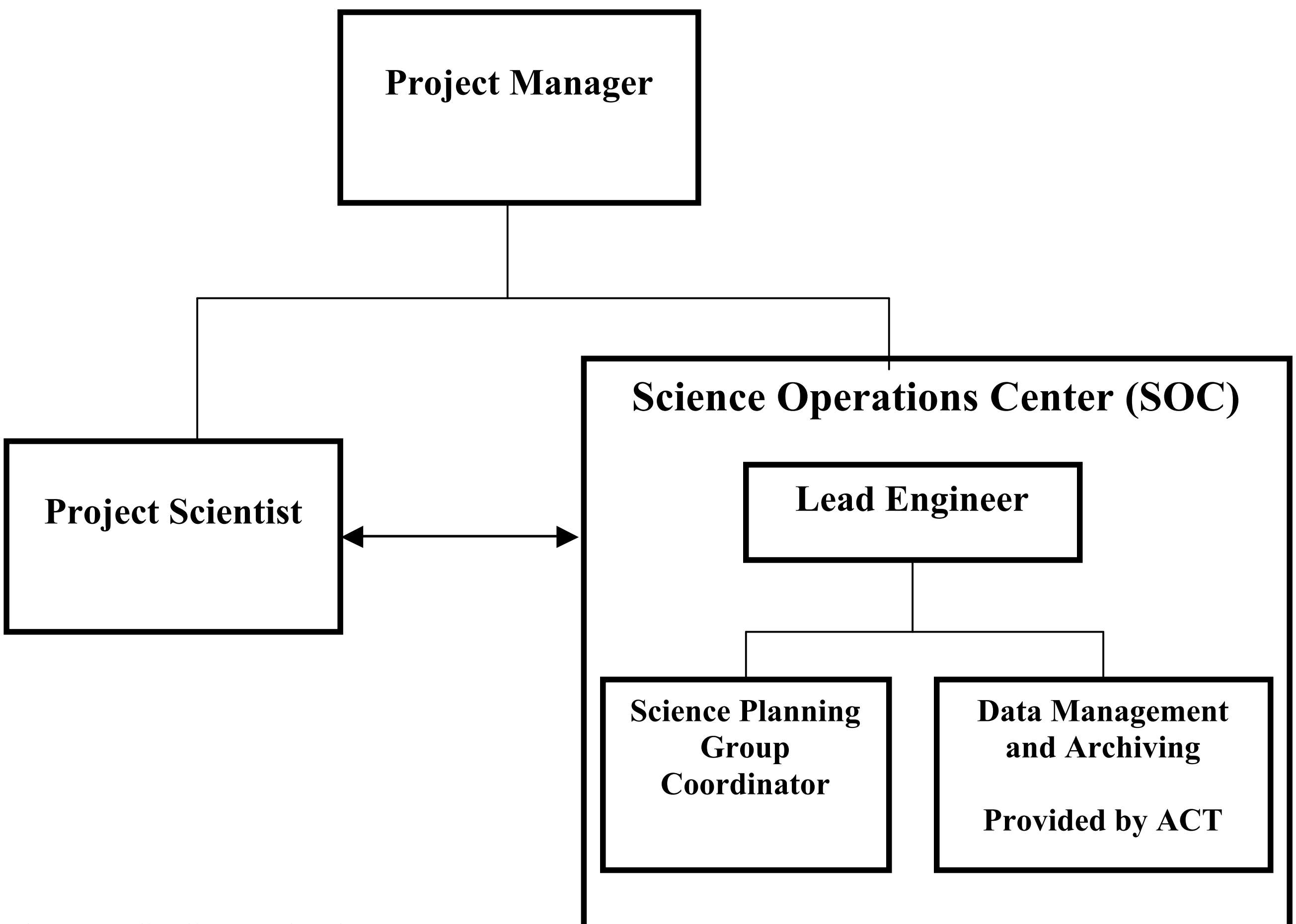

Figure 2. SOC organizational chart.

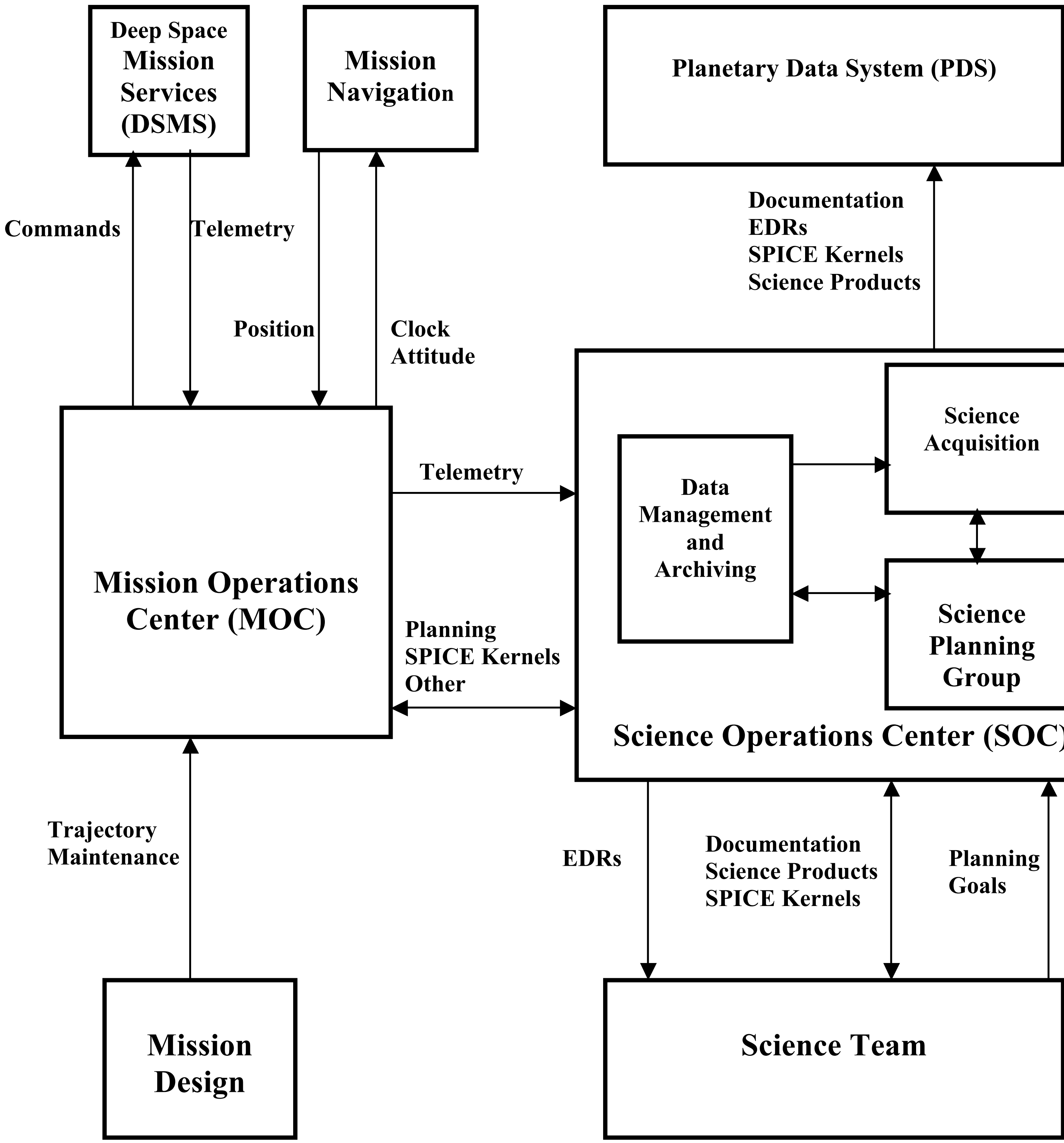

Figure 3. MESSENGER data flow

Science Operations Center

The MESSENGER SOC is the center of activity for science planning, data acquisition and analysis, and data archiving. The MESSENGER SOC, physically located at JHU/APL, is operated under the direction of its Lead Engineer who reports directly to the MESSENGER Project Manager. The Project Scientist provides guidance and requirements to the SOC Lead Engineer regarding the SOC's science requirements. Figure 2 shows how the SOC fits within the MESSENGER Project's organizational structure. The SOC supports and works with the Mission Operations Center (MOC), the Science Team, cognizant Co-Is, Instrument Scientists, and the PDS in order to fulfill its responsibilities. Figure 3 shows the informational flow between the SOC (and its subdivisions) with the MOC, Science Team, and PDS.

The SOC responsibilities can be divided into two categories: (1) those involved with science planning, data acquisition, instrument operations, and monitoring the science objective status, and (2) data dissemination to the MESSENGER Science Team, data analysis and product generation, and data archiving. The first category, referred to as "Science Acquisition", is led by JHU/APL by the Project Scientist and includes participation by the Science Team, cognizant Co-Is, Instrument Scientists, and Instrument Engineers. The second category, referred to as "Data Management and Archiving", is led by ACT and also includes participation by the Science Team, cognizant Co-Is, Instrument Scientists, and Instrument Engineers. Oversight of the SOC's science acquisition and data processing is by the Project Scientist.

Under Science Acquisition the SOC will be responsible for:

- Observation Planning
- Observation Commanding
- Validation
- Science Objective Assessment.

Observation Planning involves the planning and generation of instrument and spacecraft commands for science data acquisition. It is based on inputs from Instrument Scientists, Instrument Engineers, and the Navigation Team and spacecraft constraints from the MOC. Observation Planning is the responsibility of the Science Planning Group (SPG), a part of the SOC. Observation Commanding involves the development of instrument commands and the translation of the observation plan into command sequences for upload to the spacecraft through the MOC. Observation Commanding is also a responsibility of the SPG. Validation includes Observation Validation and Observation Quality assessment. The first validates the executed command sequences and reschedules any failed sequences necessary to fulfill the science objectives. Observation Quality is an assessment of usability of the measurements for achieving the science objectives. The assessment criteria are supplied by the Science Team to the SPG.Validation is the responsibility of the SPG. Science Objective Assessment includes the monitoring of data coverage and mission status. Science Objective Assessment is the responsibility of the SPG, who reports their assessment to the Science Steering Committee. The SPG fulfills its responsibilities using tools provided by the SOC. A detailed description of the SPG is provided in the Science Planning Group Charter, and a summary is given below.

Under Data Management and Archiving the SOC will be responsible for:

- Operations Support (both pre-flight and in-flight)
- PDS-Compliant Archive Generation

Pre-flight Operations Support provides data ingestion capabilities, product generation capabilities, and data access during instrument calibrations and instrument integration and test. In-flight Operations Support provides data ingestion capabilities, product generation capabilities, data access, and data monitoring (such as coverage, quality evaluation, and sensor performance) during the post-launch phase of the mission. Operations Support ensures access to the data and products by project personnel, particularly the Science Team. It also involves the generation of a predefined set of data products, such as SPICE files, in a timely manner. PDS-Compliant Archive Generation includes the generation, validation, and delivery of the MESSENGER archive data set. The generation of the data archive is the responsibility of the Science Team with assistance by the SOC. The SOC is responsible for preparing the instrument SIS documents that describe the archive structure and data generated and produced from each instrument's observations. The SOC supports the archive validation by clearing all liens generated by the review process on products generated by the SOC. The SOC is responsible for delivering the data archive on the schedule described in Section 6 (Policies for Release of Data and Public Information) of this document.

The SOC responsibilities outlined above flow into a set of requirements that are described in detail in the SOC Requirements Document and discussed in the Science Planning Group Charter.

Science Planning Group

The SPG is a subdivision of the SOC and is primarily responsible for fulfilling the Science Acquisition responsibilities of the SOC. A detailed description of the SPG is contained in the Science Planning Group Charter. Its responsibilities include:

- Development of instrument observing plans
- Generation of instrument commanding
- Conversion of observing plans into instrument command sequences for execution
- Validation of data
- Monitoring of data coverage
- Maintenance of an updated total mission observing plan
- Monitoring science acquisition in terms of completing mission success criteria.

The SPG reports to the MESSENGER Science Steering Committee to keep the MESSENGER project up to date on the overall status of meeting the science objectives. The MESSENGER project has input into the daily observation planning through feedback to the SPG by the Science Steering Committee.

Science Steering Committee

The MESSENGER Concept Study Report defines the purpose of the Scientific Steering Committee (SSC) as "..overseeing the entire MESSENGER mission science implementation, from instrument development through the interdisciplinary synthesis of all data sets. The members of the SSC include the Principal Investigator (SSC Chair), the Project Scientist and the Deputy Project Scientist, the Science Payload Manager, the Program Manager, and the four Science Team discipline leads.

The SSC will meet monthly during the orbital mission and as needed during cruise and flyby mission modes. The SSC will monitor the instrument payload performance and status, the status and progress of data product production, the status of scientific publications, the status of data coverage, and the status of archiving the mission success criteria, and they will make recommendations to the SPG as necessary on the basis of these issues.

Data Archive Working Group
The MESSENGER DAWG consists of representatives of the MESSENGER project and the PDS. The goals of the DAWG are to plan and ensure that PDS-compliant data archives are generated, validated, and delivered to the PDS following the MESSENGER project Archive Generation, Validation, and Distribution Plan (AGVDP).

The AGVDP will be generated by the DAWG. The purpose of the document is to define the formats and supporting deliverables, along with the data archives, that the MESSENGER project is responsible for delivering to the PDS. The document also defines what the PDS is to expect from the MESSENGER project, and what it will be responsible for making accessible to the science community.

The AGVDP will describe the specific generation, validation, and transfer through the SOC to PDS of the team's data products. The plan will specify the contents of archives, the personnel or organization responsible for generating each archive, estimates of the amount of data to be delivered, and a schedule for delivery. Instrument Scientists (see Table 1) will contribute instrument-specific sections of the document. The AGVDP will be based on the policies and procedures specified in this document.

4.2 Planetary Data System

The NASA PDS is an active archive that provides high-quality planetary science data products to the science community (Arvidson et al., 1994; McMahon, 1996). This system evolved in response to science community requests for improved availability of planetary data from NASA projects through increased scientific involvement and oversight. PDS provides access to data archives for scientists, educators, and the public.

The first objective of the PDS is to publish and disseminate documented data sets, which are of use in scientific analyses. Whereas the media of the published data vary, all PDS-produced products are peer-reviewed by scientists and data engineers to ensure that the data and the related materials are appropriate and usable. PDS data sets are typically published as archives, collections of peer-reviewed data along with documentation, ancillary information (such as calibration data), software, and any other tools needed to understand and use the data. PDS provides access to data by a system of online and compact disc archives.

The PDS is the primary organization within NASA responsible for archiving planetary data and is the primary mechanism through which the MESSENGER project will disseminate its mission data to the science community. The lead PDS node for interfacing with the MESSENGER mission is the Geoscience (GS) node at Washington University. The lead node will be supported by other PDS nodes such as the Imaging (I) node for assistance in dealing with the MDIS observations, the Planetary Plasma Interactions (PPI) node for assistance in dealing with the MAG and EPPS observations, the

Atmospheres (A) node for assistance in dealing with the MASCS observations, the Radio Sciences (RS) node for assistance in dealing with the RS observations, and the Navigation and Ancillary Information (NAIF) node for assistance in dealing with the navigation and engineering data.

The PDS Geosciences Node Manager, Raymond Arvidson, will work with the MESSENGER SOC and DAWG to ensure that overall plans are in place and that the MESSENGER project meets its archiving commitments. A PDS sub-node manager has been identified for each MESSENGER instrument (see Table 1) to facilitate the implementation of the archive plans. Relevant PDS personnel will participate in archive planning efforts for each instrument to ensure that: (a) archives are planned, generated, and reviewed using PDS standards, (b) the archiving process generates data products in pre-approved PDS standard formats, (c) archives are constructed in ways that facilitate cross-mission and cross-instrument data analyses, and (d) the PDS provides user services that allow search and access to data in ways that transcend particular instruments or data sets. This participation will be coordinated by the MESSENGER project's SOC and the MESSENGER DAWG.

The PDS is responsible for distributing the MESSENGER project archives to the broad science community after the data have been released by the project. Distribution may be done electronically via the Internet or by replication of archive volumes for delivery to users. The PDS maintains copies of project archives, and the relevant PDS discipline nodes are available to provide information and expert assistance to users of the data.

Specific functions of the PDS are to:

- support the generation of the archive by advising the project/science teams on PDS archive standards, requirements, and documentation needs. PDS will also support the data validation activity to ensure that the formal peer review process, a requirement for data ingestion into PDS, proceeds with a minimum of problems
- conduct a formal peer review of the archive, as mandated by PDS prior to acceptance of archive data
- offer support to the MESSENGER Science Team and SOC in the resolution of liens that arise in the course of the peer review
- produce archive volumes for distribution to the NASA-supported science community
- provide the data archive volumes to NSSDC.

NSSDC is responsible for long-term preservation of the MESSENGER data archive and for filling large data orders to the science community per the Memorandum of Understanding, dated January 13, 1994, between the PDS and NSSDC.

4.3 The Johns Hopkins University Applied Physics Laboratory

The JHU/APL will physically house the MESSENGER SOC. The Project Scientist will coordinate the SOC science acquisition responsibilities, with participation from the Science Team, cognizant Co-Is, Instrument Scientists, and Instrument Engineers.

The JHU/APL Media Relations Office will be the prime point of contact with the public and the media for engineering activities focused at APL. The overall objective of the Media Relations Office is to maximize the positive impact of information releases from the project. This office will:

- organize and implement press releases and/or press conferences
- facilitate release of data and information meant for consumption by the press and public, including video feeds of interviews
- review for aesthetic and editorial style materials released in hard copy and Web forms.

All releases shall have the prior approval of the PI.

4.4 Carnegie Institution of Washington

The CIW Public Relations Office will be the prime point of contact with the public and the media for the MESSENGER science activities. Press releases with science content will be delegated to the CIW or JHU/APL Media Relations Office for release as deemed appropriate by the PI. Release shall be only with the PI's prior consent.

4.5 Applied Coherent Technology

ACT is the MESSENGER sub-contractor for the SOC. Their responsibilities include providing the SOC software that enables the Science Team to access the mission data, receiving all standard products from the Science Team and storing them in PDS-compliant formats, and delivering all standard products from the Science Team to the PDS. They are responsible for producing all EDRs in a format usable to the Science Team and acceptable by the PDS for archiving. They provide cleaned and merged telemetry for all instruments and the spacecraft for use in producing the higher-level standard products by the Science Team.

5.0 Data Flow within the MESSENGER Project

Figure 2 summarizes and maps the flow of data and information within the MESSENGER project for achieving its science goals and objectives. The mission science objectives correspond to measurement requirements. It is the task of the SOC to translate these measurement requirements into instrument observation plans and commands. These are transferred to the Mission Operations Center (MOC) for integration with the spacecraft and navigation commands and relayed to the spacecraft through the DSN. The resulting observations are then downlinked from the spacecraft through the DSN back to the MOC. The MOC then transfers all science data and related navigation, commanding history, and housekeeping (both instrument and spacecraft housekeeping) information to the SOC. The SOC, through interactions with the Science Team, Instrument Scientists, and Instrument Engineers, then performs data validation, calibration, and product generation.

5.1 Mission Operations Center (MOC)

The data management responsibilities of the MOC include:

- merging instrument commanding with spacecraft and navigation commanding for upload to the spacecraft through the DSN
- receiving all science data from the spacecraft through the DSN
- providing the SOC with the downlinked science data, related telemetry, navigation, and housekeeping data

- working with the Navigation Team and the NAIF node of the PDS to provide SPICE information to the SOC for higher-level data product production and archive.

5.2 Navigation Team

The data management responsibilities of the Navigation Team include:

- supplying optical navigation observing requirements to the imaging team for inclusion in the observation command load for the MDIS instrument
- supplying accurate SPICE information to the SOC for Science Team use in data product generation and for data archiving.

5.3 Mission Design and G&C Team

The data management responsibilities of the Mission Design and G&C Team include

- working with the Navigation Team for orbital maneuver design and defining orbital maneuver targets
- providing orbital maneuver information and parameters to the MOC for execution .

5.4 Science Operations Center (SOC)

The SOC is managed under the auspices of the Project Scientist. The management of the SOC is led by ACT, with key roles played by JHU/APL and the Science Team. The SOC is physically located at JHU/APL.

The core of the data management responsibilities are those of the SOC. They include

- support for ground and in-flight instrument calibrations
- science planning, including instrument operations and commanding, data acquisition and validation, and maintaining a status report on the mission's progress in meeting its science objectives
- dissemination of the data to the MESSENGER Science Team
- keeping an internal archive of the science data products produced by the Science Team for later archiving to the PDS
- archiving of all mission data (including instrument calibration data, and all standard data products)
- dissemination of selected data products to the project's education/public outreach effort.

5.5 Science Team

The Science Team receives all mission science data and supporting ancillary data. Their main responsibility is the scientific analysis of the MESSENGER data set and the production of the higher level data products described in Section 3. The Science Team is responsible for the delivery of all CDRs, DDPs, and DAPs to the SOC for archiving by the PDS.

The Science Team is responsible for defining data quality assessment criteria for the SPG. The SPG, whose members are drawn in part from the Science Team, will apply these data quality assessment criteria to fulfill some of the SOC data validation requirements. The Science Team provides guidance to the SPG for meeting the mission science objectives through the Science Steering Committee.

6. Policies For Release Of Data And Public Information

6.1 Data Rights and Release Policy

Because of the expected widespread scientific and public interest in new results from Mercury and the strong commitment of the MESSENGER project to releasing data on a timely basis, it is important to establish a clear policy for data dissemination to both the general public and the science community. The MESSENGER project recognizes the importance of disseminating the data and measurements it will acquire during its mission in a prompt and timely fashion. As stated in the MESSENGER CSR, the project is committed to providing all mission data as soon as processing and validation are complete, thus insuring the highest quality control on all data released.

Table 7 provides the schedule for delivery of EDRs from the MESSENGER project to the PDS, as specified in the MESSENGER CSR. The CSR does not specify a schedule for delivery of the Venus flyby data. Based on the Mercury flyby delivery schedule, the MESSENGER project will delivery all Venus flyby data after the completion of the second Venus flyby. The MESSENGER CSR commits the project to delivering all RDRs to the PDS within 12 months of the end of mission.

Table 7. EDR Delivery Schedule to PDS

Mission Data	PDS Delivery Date in CSR	MESSENGER Planned Delivery Date
Venus flyby 1	Not specified	6 months after 2nd Venus flyby encounter
Venus flyby 2	Not specified	6 months after 2nd Venus flyby encounter
Mercury flyby 1	After 2nd Mercury flyby encounter	6 months after 2nd Mercury flyby encounter
Mercury flyby 2	After flyby encounter	6 months after 2nd Mercury flyby encounter
Mercury orbit	6 months after end of mission (18 months after Mercury orbit insertion)	6 months after end of mission (18 months after Mercury orbit insertion)

The generation/validation time period for standard data products is defined to be the period from receipt of science packets containing raw data at instrument processing facilities until release of archive volumes to the PDS. The archive volumes will include, as appropriate, all EDRs, RDRs, ancillary data, relevant software, and documentation describing the generation of the products.

The calibration data, a subset of ancillary data, is required for the interpretation and understanding of the science data set. The calibration data has both on-ground and in-flight components. The delivery schedule of this subset of ancillary data is as follows:

- On-ground calibration data will be provided to the SOC at least 3 months prior to launch, including all relevant documentation and labels.
- On-ground calibration data will be delivered and archived to the PDS by the SOC within six months after launch.
- In-flight calibration data collected to date will be delivered to the SOC prior to the first Mercury

flyby, including all relevant documentation and labels.

- In-flight calibration data collected to date will be delivered and archived to the PDS by the SOC within six months of the second Mercury flyby.
- Subsequent in-flight calibration data will be delivered to the SOC prior to the end of the mission.
- A final delivery of calibration data will be made to the PDS via the SOC within six months of the end of mission, in conjunction with the delivery to PDS of the Experimental Data Records (EDRs). This will include references to calibration papers with complete descriptions of data and calibration algorithms published in peer-reviewed literature.

To ensure rapid dissemination of new and significant information, the PI and the PS will coordinate release of a significant subset of data earlier as a form of public outreach and education. These releases will typically be available within a week of data receipt. Postings on the World Wide Web (WWW) will be used as a cost-effective way for widespread dissemination of these special products. The posted data may include images, derived spectra, topographic information, and other forms of data that illustrate new and significant results. Postings will include documentation. These data releases will conform to the Public Information Release Policy (Section 6.2 below).

During the generation/validation period, any scientific use and analysis of raw and derived products from a particular instrument, use of results from unpublished papers derived from such analysis, or posting of scientific analysis of data on the WWW for public outreach and education, requires the explicit agreement of the PI.

In the event of anomalies, data should be archived using stated policies, unless observational, personnel, and/or financial constraints force the need for a longer period between data receipt and transfer of archives to the PDS.

6.2 Public Information Release Policy

The guidelines for releasing materials to the public, as stated in the MESSENGER CSR, are as follows.

- Preliminary data will be released on a public web site within ~72 hours of downlink.
- Public dissemination of selected images and data will occur immediately following calibration with the best currently available calibration algorithms.
- Optimal use will be made of the World Wide Web (WWW) to provide results to associated educational and outreach endeavors.

Public information release includes press conferences, postings on the WWW, and printed materials concerning both mission operations and scientific analyses. Additional policy statements for Public Information Release for the MESSENGER project are:

- Information concerning spacecraft and instrument anomalies may be released only by the MESSENGER Project Office, in coordination with NASA Headquarters and the PI. Information concerning significant scientific results may be released during press conferences, press releases organized by the MESSENGER Project Office and the JHU/APL's Media Relations Office, and on the WWW, and in coordination with NASA Headquarters and relevant members of the Science Team, but only with the concurrence of the MESSENGER PI.

- Information concerning scientific results from any instrument study may be released by a Co-Investigator before it is deposited in the PDS, but only with the concurrence of the MESSENGER PI.
- The MESSENGER Project Office must receive, 48 hours in advance, a copy of any released material (e.g., images, spectra, captions, summary of results), a schedule for the release, and a statement of the mechanisms for release. The intent is not to require concurrence for the release, but only to make sure that the MESSENGER Project Office, JHU/APL's Media Relations Office, and NASA Headquarters are informed of the releases before they happen.

The primary tool for dissemination of the MESSENGER data set to the general public will be the WWW. An outline of the MESSENGER web site is included in Appendix A. Those portions of the web site pertaining to data dissemination are (1) the Image of the Day, (2) the Mission/Monthly Status Reports, (3) the Mission/Movies & Animation, (4) the Science Operations, (5) the News Room/Gallery/Images, and (6) the News Room/Mission Information/Press Kit. Also part of the MESSENGER web site is a section dedicated to education. The purpose of this section is to inform the general public about the science and engineering aspects of our mission. It will provide tools for educators and opportunities for interactions with the MESSENGER team. This education section of the web site is focused on the learning experience rather than dissemination of data.

Image of the Day

Selected images and data will be released on a daily basis after calibration with the best available calibration algorithm at the time the images and data are downlinked from the spacecraft. Captions will be included with the released images and data that describe the material and its scientific importance. An archive of the "Image of the Day" will be maintained and accessible through several venues on the web site.

Mission/Monthly Status Reports

Engineering and science status reports to NASA Headquarters will be produced on a monthly basis. The most current report will be available on this portion of the web site, with an archive to past reports. These reports may include new science developments and discoveries and will discuss the latest science results from the mission.

Mission/Movies & Animation

The MESSENGER project will produce animations describing the mission and movies generated from images acquired by the spacecraft. Several image acquisition sequences are being planned with the goal of generating movies from the images. These will be made available to the general public through the web site.

Science Operations

This portion of the MESSENGER web site will contain five separate sections dealing with the status and dissemination of the MESSENGER mission data and data products. The first section, Observation Planning, is a description of the planned observations on a monthly time schedule. The second section, Data Status, focuses on the data acquisition process: what observations are on the solid-state data recorder, which observations have been downlinked, and a pointer to currently processed and validated raw data (experimental data records). The third section, Science Publications, is focused on data and data products released through peer-reviewed journals. This will point to a reference list of published papers (with links to the relevant journals) in addition to a sub-section containing published data products in a downloadable electronic format. The fourth section, Science Presentations, will contain a calendar of scheduled talks relevant to MESSENGER science questions and an archive of science meeting abstracts and selected viewgraph sets from the MESSENGER Science Team. The final section, Science Focus: Month Year, will be a monthly science discussion highlighting a member of the Science Team discussing interesting science returns from the MESSENGER mission. This site may link to the Education/MESSENGER classroom/Community Forum/Scientist of the Month portion of the web site.

News Room/Gallery/Images
The intent of the News Room section of the web site is to provide an information resource for the media. The Gallery/Image section of this resource will point to the "Image of the Day" archive.

News Room/Mission Information/Press Kit
The MESSENGER project will be producing press release materials in association with major mission events, press conferences, and scientific meetings. For example, press release materials (Press Kits) will be generated in association with launch, flyby encounters, and Mercury orbit insertion. Electronic versions of these materials will be made available to the general public via this portion of the MESSENGER web site.

While the MESSENGER project is committed to provide information to the general public in a timely fashion, the MESSENGER project does not plan to archive any education and public outreach products with the PDS. The MESSENGER Education/Public Outreach Team will maintain and archive all E/PO products.

6.3 Release Policy to Science Community

The guidelines for releasing materials to the scientific community, as stated in the MESSENGER CSR, are as follows.

- All data, applicable housekeeping, and calibration algorithms will be released to the PDS within six months of the end of mission (flyby data will be released within six months of the second flyby).
- Data products of scientific interest will be disseminated in electronic and printed formats.
- In parallel with final archiving at the PDS, scientific results will be shared with the science community via scientific meetings and peer-reviewed publications.
- In recognition of the necessity and responsibility for providing fully documented data sets in a timely manner to maximize the science return from the mission, optimal use will be made of the PDS and the WWW to provide results to the scientific community.

Dissemination or data release in electronic format is defined as release through the WWW, whereas the release in printed format (excluding peer-reviewed publications) is defined as the release of selected materials in hardcopy form, such as through press releases, press kits, and education program materials. Table 8 (taken from the CSR) summarizes the deliverables to the PDS along with delivery guidelines and schedule.

Table 8. Data Product Delivery (taken from CSR Table F-6-2)

Deliverable	Source	Web Display	Submission
Flight instrument data	SOC	Immediate	EOM + 6 mo.
Navigation and housekeeping data	SOC	Immediate	EOM + 6 mo.
Data products, Table D-1-1	Science Team	Monthly	EOM + 1 yr
Analysis products, Table D-1-1	Science Team	Receipt + 2mo.	EOM + 1 yr

The MESSENGER project is committed to providing all mission data to the scientific community as soon as processing and validation are complete, thus insuring the highest quality control on all data released to the science community. The primary mechanism for data distribution and release is through data archiving with the PDS. The PDS was established for the purpose of archiving all NASA mission data and is the primary venue for MESSENGER's data release policy to the science community. All scientific data and data products will be delivered to the PDS through the MESSENGER SOC. While it is the responsibility of the MESSENGER Science Team and the cognizant Co-Is to generate all data products, the delivery of these products will be conducted through the SOC.

In concert with the data archiving process, data and analysis products of scientific interest will be disseminated in electronic and printed formats and scientific results will be shared via scientific meetings and peer-reviewed publications.

The MESSENGER CSR commits to the delivery of all EDRs to the PDS within six months of the end of mission. The schedule of EDR deliveries is summarized in Table 7. While the CSR does not specify a delivery date for the Venus flyby observations, it is the intent of the MESSENGER project to submit the EDRs from these set of observations within six months of the second Venus flyby.

In parallel with the archival process being conducted through the PDS, EDRs will be made available through the MESSENGER public web site via the Science Operations/Data Status section of the site. Processed and validated EDRs for completely downlinked days will be made available to the public and scientific community through a link from this site to a project-supported archive. In this manner, flight instrument data are made available immediately (see Table 8) in electronic format via the WWW.

The MESSENGER CSR states that all data products will be archived with the PDS within 12 months of the end of mission. MESSENGER data products include CDRs, DDPs, and DAPs. The MESSENGER project is committed to deliver a final calibration algorithm and calibrated post-launch data within 12 months of the end of mission.

In parallel with the archiving of the MESSENGER EDRs and CDRs with the PDS, the DDPs and DAPs will be presented at scientific meetings and published in peer-reviewed journals. Commensurate with their presentation and publication the DDPs and DAPs will be released in electronic format to the science community through the public web site. A portion of the public web site, titled Science Operations, will focus on the dissemination of scientific results. This portion of the public web site has a section (Data Status) where currently processed and validated EDRs are available. In another section (Science Publications), an archive will be maintained of published DDPs and DAPs. The Science Operations/Science Publications portion of the web site may include references to copyrighted articles (with pointers to the journal web sites), copies of meeting abstracts, and copies of presentation materials. These DDPs and DAPs will be released via the web site within 2 weeks of publication or presentation.

6.4 Data Release Acknowledgement Policy

In any release of data or information as described in Sections 4.1 and 4.2 above, appropriate credit will be given to all entities involved, including the Science Team member(s), his or her home institution, JHU/APL, supporting institutions (as appropriate), and NASA. The credit will appear on public web sites that contain data releases and on documentation that accompanies the data products.

6.5 International Traffic in Arms Regulations (ITAR)

The information referred to in this document is being acquired through fundamental research in science and engineering at an accredited institution of higher learning in the U.S. The type of information being placed in the public domain is information that is ordinarily published and shared broadly in the scientific community. The information is not restricted for proprietary reasons. The U.S. Government has not placed specific access and dissemination controls on the information. (See [CFR] Section 120.11(8).)

7.0 Archive Process

The MESSENGER archive will contain standard data products from each of the instruments, navigation and geometry data from the SPICE information system, ancillary data, software, and sufficient documentation to ensure that future scientists can understand and use the archive. The science data products form the core of the archive and are discussed in Section 3.

Production of this archive involves design of the archive structure and contents, generation of the archive components, validation, and final packaging and delivery. The archive production is described in detail in the AGVDP. High-level descriptions of the planning and design, generation, validation, and delivery are presented below.

7.1 Planning and Design

The total volume of EDRs expected to be downlinked from the MESSENGER mission is on the order of 70 Gbits. The final MESSENGER archive to the PDS may be on the order of 300 to 400 Gbits. The archive will be delivered using a physical medium such as CDs or digital versatile disks (DVDs), as appropriate. The data will be ordered first by time, then by instrument, and further divided by type of data, if relevant. Figure 3 illustrates the structure of a typical volume of the archive.

The details of what components are included in the archive and how they are grouped into data sets, subdirectories, and files comprise the design of the archive. The format and content of data products are described in detail in the individual instrument SIS documents, which have been created by the SOC lead with inputs from the relevant Instrument Scientists and cognizant Co-Is. The format and content of the archive volumes are described in the Archive Generation, Validation, and Dissemination Plan (AGVDP), which is generated by the MESSENGER DAWG. Archive plans within the AGVDP will be developed for each instrument in cooperation with the SOC to ensure that archive generation is accomplished on schedule and to provide a forum for validation.

Preparation for generating project data archives involves designing the data products and the archive volumes on which they will be stored and developing the systematic generation, validation, and distribution procedures for these archive volumes. The plans shall be documented in the AGVDP.

The PDS has developed a set of software tools useful for generating archive volumes. They include tools for reading, writing, and validating labels for data products, generating data dictionaries and index tables, and validating archive volumes. For more information see the PDS World-Wide Web site at *http://pds.jpl.nasa.gov/*.

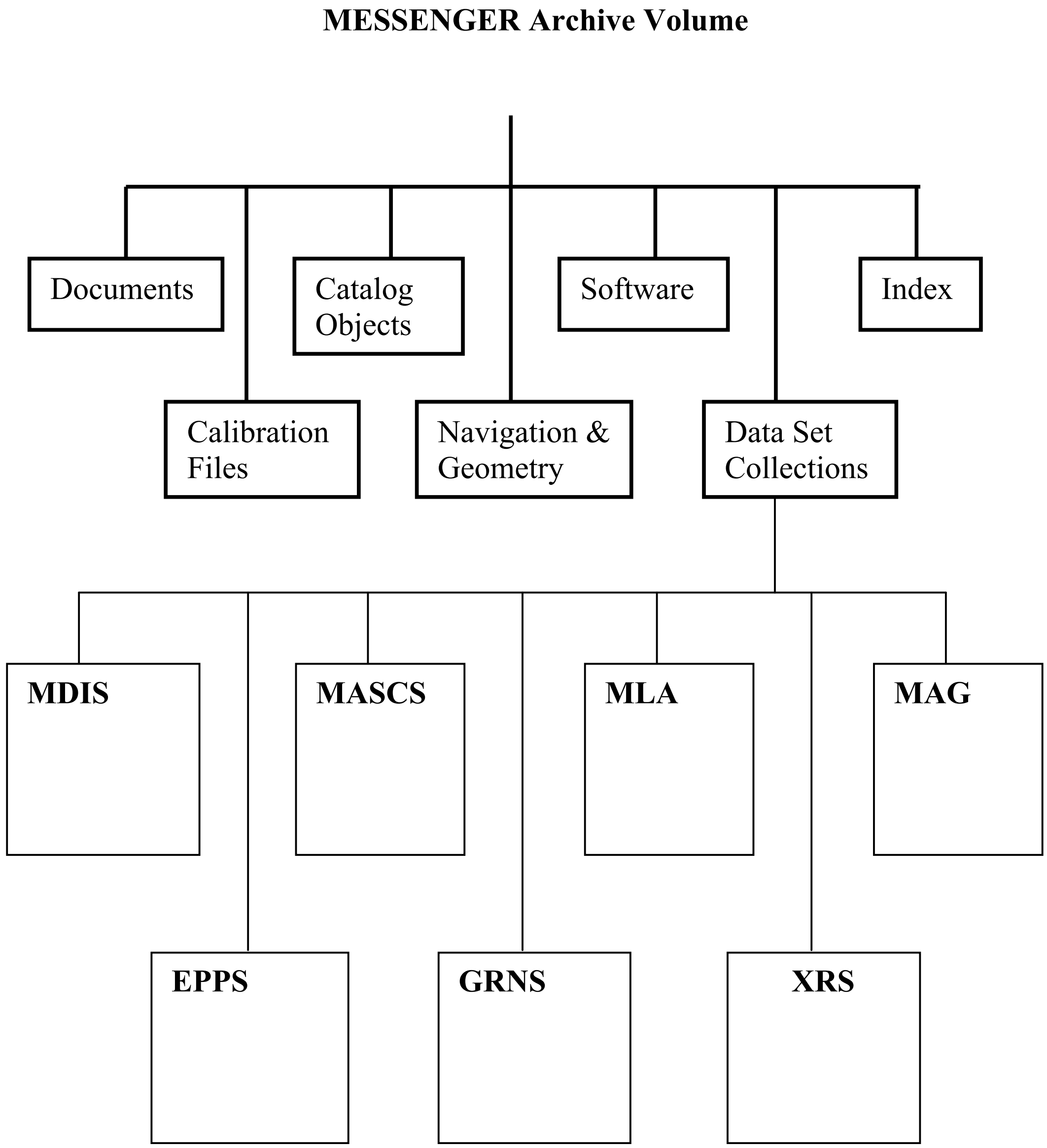

Figure 4. General structure of a typical volume of the MESSENGER archive.

7.2 Generation

An *archive* consists of one or more data sets along with all the documentation and ancillary information needed to understand and use the data. Thus defined, an archive is a logical construct that is independent of the medium on which it is stored.

An *archive volume* is a unit of medium on which an archive is stored; for example, one CD-ROM. When an archive spans multiple volumes, they are called an archive volume set. Usually the documentation and some ancillary files are repeated on each volume of the set, so that a single volume can be used alone.

Whole or partial archives may be placed online for convenient distribution via the Internet. However, to ensure long-term viability, archives must also be stored offline on physical archive volumes. The choice of storage medium will depend on available technology. It should be a stable, industry-standard medium intended for long-term storage. The standard media for long-term storage are CD-ROMs and DVD-ROMs.
Responsibility for generating archive components is specified in Section 4. Science data products will be generated in PDS-compliant formats. Each data file (data table or image file) will be in a format approved by PDS and will be accompanied by a PDS "label," which describes the content and structure of the accompanying data file. Navigation and geometry data necessary to interpret the data (e.g., spacecraft ephemeris and attitude records, command histories, and spacecraft housekeeping files) will be provided as ancillary archive components. The source code of all software to be provided with the archive will be collected and documented. In addition, files documenting the archive components will be prepared by the parties generating the data. In general, all information necessary to interpret and use the data are to be included in the archive.

The PDS "catalog objects" are files that document the mission, spacecraft, instruments, and data products. The catalog objects take the form of templates which must be filled out with prescribed information. The required catalog objects are the “mission template,” describing the MESSNEGER mission as a whole, the "instrument host template" describing the spacecraft, one instrument template for each instrument, and one data set template for each data set. These templates will contain information needed to document the archive and enable future scientists to make correct use of the data when mission personnel are no longer available to support them. The PDS will fill in the formal portions of the catalog objects, requiring only text descriptions of the mission, spacecraft, instruments, and data sets from MESSENGER.

The Navigational and Ancillary Information Facility (NAIF) will assist the SOC in generating an archive volume set of all SPICE (Navigation and Geometry) data.

7.3 Validation

Data validation falls into two types, validation of the data itself and validation of the compliance of the archive with PDS archiving requirements. The first type of validation will be carried out by the Science Team, and the second will be overseen by the PDS, in coordination with the Science Team.

The formal validation of data content, adequacy of documentation, and adherence to PDS archiving standards is subject to an external peer review. The peer review will be scheduled and coordinated by the PDS. The peer review process may result in "liens," actions recommended by the reviewers or by PDS personnel to correct the archive. All liens must be resolved by the dataset provider: the SOC for Level-1 data, and the Science Team for higher-level data products, calibration data, and calibration algorithms. Once the liens are cleared, PDS will do a final validation prior to packaging and delivery.

The SOC will periodically report results of validation to the Science Steering Committee. If the volumes are approved for release by the Project, then the SOC will transfer the archives to the PDS, based on the release schedule specified by the project's Archive Generation, Validation, and Distribution Plan.

7.4 Delivery

The delivery schedule for archive products is discussed in Section 3. However, a summary of the archive delivery schedule is as follows:

- all on-ground calibration data will be delivered within 6 months of launch
- all in-flight calibration data will be delivered within 12 months of End of Mission (EOM)
- all Venus flyby data will be delivered within 6 months of the 2nd Venus flyby
- all Mercury flyby EDRs will be delivered within 6 months of the 2nd Mercury flyby
- all post-launch EDRs will be delivered within 6 months of EOM
- all post-launch CDRs, DDPs, and DAPs, along with final calibration algorithms, will be delivered within 12 months of EOM.

8.0 Definitions of Terms

Ancillary Data – Non-science data need to generate calibrated or resampled data. Any information needed to create any of the standard data products, such as CDRs, DDPs, and DAPs.

Archive – An archive consists of one or more data sets along with all the documentation and ancillary information needed to understand and use the data. An archive is a logical construct independent of the medium on which it is stored.

Archive Volume, Archive Volume Set – A volume is a unit of medium on which data products are stored; for example, one CD-ROM. An *archive volume* is a volume containing all or part of an archive; that is, data products plus documentation and ancillary files. When an archive spans multiple volumes, they are called an *archive volume set*. Usually the documentation and some ancillary files are repeated on each volume of the set, so that a single volume can be used alone.

Calibrated Data Records – CODMAC Level-2 data that have been located in space and may have been transformed (e.g., calibrated, decompressed, rearranged) in a reversible manner and packaged with needed ancillary and auxiliary data (e.g., radiances with the calibration equations applied).

Data Product – A labeled grouping of data resulting from a scientific observation, usually stored in one file. A product label identifies, describes, and defines the structure of the data. An example of a data product is a planetary image, a spectrum table, or a time series table.

Data Set – An accumulation of data products. A data set together with supporting documentation and ancillary files is an archive.

Derived Data Products – CODMAC Level 3 or 4 standard data products. Irreversibly transformed (e.g., resampled, remapped, calibrated) values of the instrument measurements (e.g., radiances, magnetic field strength).

Derived Analysis Products – CODMAC Level 3 through 5 standard data products. Irreversibly transformed (e.g., resampled, remapped, calibrated) values of the instrument measurements (e.g., radiances, magnetic field strength). Data that have been resampled and mapped onto uniform space-time grids. The data are calibrated and may have additional corrections applied.

Engineering Products – A subset of Ancillary Data, often in the form of instrument settings (such as voltages, current, and temperature), and spacecraft health status.

Experimental Data Records – NASA Level 0 data for a given instrument; raw data.

Navigation Data - A subset of Ancillary Data, often in the form of SPICE files, that aid the interpretation and processing of standard data products and are needed for producing the higher-level standard data products, such as the DDPs and DAPs.

Packetized Data Records – Telemetry data stream as received at the ground station, with science and engineering data embedded.

Processed Data – CODMAC Level 3 or higher standard data products.

Project Data – Any data products produced by the MESSENGER project for archive to the PDS.

Raw Data – Same as Packetized Data Records

Raw Science Data – Same as Raw Data and Packetized Data Records.

Reduced Data Records – Science data that have been processed from raw data to NASA Level 1 or higher. See Table 3 for definitions of processing levels.

Science Data – PDRs, EDRs, and RDRs that have scientific value.

SPICE Data – A suite of elemental ancillary data sets, often called kernels. They include spacecraft ephemeris, planet/satellite ephemerides, instrument information, camera orientation, and event information.

Standard product – A data product that has been defined during the proposal and selection process and that is contractually promised by the PI as part of the investigation. Standard data products are generated in a predefined way, using well-understood procedures, and processed in "pipeline" fashion.

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10.0 Acronyms

Table 9. Acronym defintions

Acronym	Definition
ACT	Applied Coherent Techonolgies
AGVDP	Archive Generation Validation and Dissemination Plan
AM	Atmosphere and Magnetosphere Group
APL	Applied Physics Laboratory
BP	Borated Plastic
BST	Burst data
CDR	Calibrated Data Record
CIW	Carnegie Institution of Washington
CODMAC	Committee On Data Management And Computation
CSR	Concept Study Report
DAP	Derived Analysis Product
DAWG	Data Archive Working Group
DDP	Derived Data Product
DEC	Declination
DN	Data Numbers
DNL	Differential Non-Linearity

DSN	Deep Space Network
EDR	Experimental Data Record
EPPS	Energetic Particle and Plasma Spectrometer
EPS	Energetic Particle Spectrometer
FIPS	Fast Imaging Plasma Spectrometer
FITS	Flexible Image Transport Standard
FOV	Field of View
GC	Geochemistry Group
GDS	Ground Data System
GG	Geology Group
GP	Geophysics Group
GRNS	Gamma-Ray and Neutron Spectrometer
GRS	Gamma-Ray Spectrometer
GS	GeoScience
InGaAs	Indium Gallium Arsenide
INL	Integral Non-Linearity
JHU/APL	The Johns Hopkins University/Applied Physics Laboratory
LHK	Low-rate Housekeeping
LSB	Least Significant Bit
MAG	Magnetometer
MASCS	Mercury Atmosphere and Surface Composition Spectrometer
MD	Mission Design
MDIS	Mercury Dual Imaging System
MESSENGER	MErcury Surface Space ENvironment GEochemistry Ranging
MLA	Mercury Laser Altimeter
MOC	Mission Operations Center
NAIF	Navigation and Ancillary Information
NAV	Navigation
NSSDC	National Space Science Data Center
NS	Neutron Spectrometer
PAD	Pulse Amplifier Discriminator
PDR	Packetized Data Record
PDS	Planetary Data System
PHA	Pulse-height analysis
PI	Principal Investigator
PLR	Project Level Requirements
PPI	Planetary Plasma Interactions
PS	Project Scientist
RA	Right Ascention
RDR	Reduced Data Record
RS	Radio Science
S/C	Spacecraft
SIS	Software Interface Specification
SOC	Science Operations Center
SPG	Science Planning Group
SPICE	Spacecraft ephemeris, Planet/satellite ephemeris, Instrument information, Camera orientation, Event information.
SSC	Science Steering Committee
SSD	Standard Science Data
SSR	Solid State Recorder
ST	Science Team
TTSP	Time To Second Pulse

UTC	Universal Time ???
UVVS	Ultra-Violet Visible Spectrometer
VIRS	Visible Infrared Spectrometer
XRS	X-Ray Spectrometer